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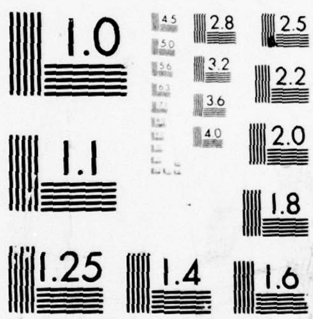

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13 LEVEL II

COSTS AND BENEFITS OF REQUIRING NEW PRODUCTION OF OLDER AIRCRAFT TYPES TO MEET AMENDED NOISE STANDARDS

C.F. Day
E.D. Studholme

September 1979

FINAL REPORT

Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

Prepared for

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NOTICE

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16. Abstract

This report examines costs and benefits associated with requiring new production of older aircraft models to meet amended noise standards. Two cases are examined: (1) all aircraft produced after 1983 must meet a noise emission standard halfway between Stage 2 and Stage 3 limits; and (2) all aircraft produced after 1985 must meet Stage 3 noise standards. The cost elements are combined and expressed as a change in direct operating costs in either cost-per-passenger mile or cost-per-aircraft mile, as appropriate. Noise benefits are estimated in terms of the change in area under a 100 EPNL contour resulting from the amended standards.

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CHAPTER 1

INTRODUCTION AND SUMMARY OF RESULTS

BACKGROUND

This report examines costs and benefits associated with requiring new production of older aircraft models to meet amended noise standards. Two cases are examined: (1) all aircraft produced after 1983 must meet a noise emission standard halfway between Stage 2 and Stage 3 limits; and (2) all aircraft produced after 1985 must meet Stage 3 noise standards. In general, elements of cost included in the evaluation are:

- Development cost associated with each technological fix applied to reduce noise emissions
- Incremental change in unit aircraft production costs
- Operating cost penalty or reduction resulting from the aircraft modification.

These components were combined and expressed as a change in direct operating costs in either cost-per-passenger mile or cost-per-aircraft mile, as appropriate. Benefits from the proposed change in regulation were measured in terms of the change in area under a 100 ENPL contour resulting from the modification.

The report is preliminary in nature and designed to provide the best information available at this time to assist the Federal Aviation Administration in the preparation of an Advanced Notice of Proposed Rulemaking (ANPRM).

MAJOR ISSUES ADDRESSED

The major issues addressed include the following:

- Identification of candidate current production aircraft that meet Stage 2, but not necessarily Stage 3, noise limits
- Identification of feasible modifications which would reduce candidate aircraft emissions by a significant degree
- Costs, expressed in terms of cost-per-seat-mile or cost-per-aircraft mile, of potential aircraft modifications
- The potential market for candidate aircraft with particular emphasis on small, short/medium haul transports
- The impact of Stage 3 certification on aircraft performance guarantees
- Benefits from the proposed change measured in terms of community impacts

Although these issues go somewhat beyond the intended scope of work, the findings are significant in evaluating the proposed change in noise regulations. The depth of the analysis performed is, however, insufficient for this study to be considered a complete regulatory analysis. The results will, nevertheless, be useful in formulating an ANPRM.

SUMMARY OF RESULTS

Candidate Aircraft, Technology, Cost

Current production aircraft which do not meet Stage 3 noise limits include some models of the 747, DC10-30 and all narrow body aircraft utilizing the JT8D engines. The technologies available for noise reduction include noise treatment of engines and nacelles, aerodynamic redesign, and the substitution of quieter for noisy engines. In addition, mixer technology can be incorporated into low bypass ratio engines like the JT8D.

It appears that some 747 versions can be modified to meet Stage 3 standards with only minor impacts on aircraft-mile or seat-mile costs. The DC10-30 presents a more difficult problem and no specific technology application has,

as yet, been developed. Modification to Stage 3 seems practical, however, but only with a substantial increase in per mile or per seat-mile costs.

No economically feasible technology is currently available to enable current production narrow body aircraft (727, 737, DC9) to meet Stage 3. Replacing the JT8D with a high bypass ratio engine is feasible, but the engine available (or planned) dictates a body stretch to retain competitive seat-mile costs. Note, for example, that the refanned DC9-30 is substantially larger than its prede- cessors. Douglas, at this time at least, has no plans to modify existing DC9s (-10, -30, and -50 models) to meet a Stage 3 require- ment. Boeing has examined alternative engine-airframe combinations for both the 737 and 727, but no plans for production have been announced.

Noise emissions from these JT8D aircraft can be reduced substantially -- 3dB or more -- using the mixer technology developed in part with FAA funding. Additional development work by both the airframe and engine producers is required and some airframe-engining mating problems must be solved before the mixer can be used on current production aircraft. The estimated cost of this modification for standard JT8D engine models is approximately $80,000 per engine.

100-Seat Aircraft Problem

Imposing a Stage 3 requirement on future production of current wide body aicraft impacts a few models but should not have a major impact on the market potential for this class of aircraft. Alternatives, perhaps on a next-best basis, will be available for those models which cannot meet the Stage 3 requirement. The Stage 3 requirement would, however, virtually eliminate the producton of JT8D aircraft with a consequent impact on the airline's ability to provide jet service to small and medium sized communities.

Service to most small and medium sized communities consist of what can best be characterized as low-density routes. Since the number of passengers desiring service is relatively small, aircraft cost per mile rather than cost

per seat-mile is controlling for equipment selection. Almost all jet service to these airports is provided by JT8D aircraft. Two-engined jets, the 100-seat aircraft, dominate this segment of the airline market.

There are no attractive alternatives to current 737s and DC9s to serve this market. Production of these aircraft will continue at high rates at least through 1982 and a smaller but significant potential market exists for the post-1985 time period. It is possible that many of the small/medium sized communities can be served by 40 to 50 seat turboprop aircraft, but only at increased cost to travelers and/or continuing subsidies to operators.

Reduction of Noise Impacts

Early implementation of Stage 3, if achieved, will result in substantially reduced single event contours -- about 85 percent for 727s and about 75 percent for 737/DC9s. Industry studies show, however, that early implementation will have a marginal impact at best on community noise problems (measured in 1990). JWN analyses tend to confirm this but show that the substitution of Stage 3 for Stage 2 aircraft will allow many more operations at a given airport with no increase in noise impacts. We believe this is an important factor since many airports have state or self-imposed noise limits.

Use of a mixer will allow JT8D powered aircraft to lower the noise, but not to meet Stage 3 limits. Single event contour areas would be reduced by 45 percent for the 727 and 25 percent for the DC9/737 (35 - 40 percent at 90 EPNdB). Rather gross estimates indicate that the cost of the mixer will increase aircraft operating costs (including capital recovery) by less than 1 percent.

Practical Problems of Certification

Certification of current production aircraft to Stage 3 is expensive and presents difficult technical problems. A full certification test costs the aircraft producer more than $1 million. Moreover, uncertainties associated with modifications and certification tolerances makes recertification to Stage 3 a risky process for producers.

The manufacturers are offering a number of derivative versions of current wide body aircraft which include various engine-airframe combinations. As noted above, some existing models will require modification, often slight, to meet Stage 3. Producers may face serious problems in providing performance guarantees in many cases because of the uncertainties associated with certification, particularly when the noise reductions required begin to approach the measurement tolerances of the certification equipment. Some method for certifying changes in sound levels resulting from changes in airframe or engines would be preferable to complete recertification.

Other Factors

There are several other factors associated with the proposed change in noise rules which should be noted. These are:

- Market Impact - The potential unconstrained U.S. market for JT8D aircraft (excluding the DC9-30) for the period 1985-90 is 15-25 aircraft per year, a total of perhaps 120 aircraft. The proposed change to Stage 3 would eliminate these sales while an amendment to a standard compatible with mixer technology would have little or no market impact.

- Timing of the Proposed Change - The timing of the proposed rule does present industry with some special problems. Douglas, for example, while not necessarily opposing a production cutoff, suggests that it should not become effective until industry has a chance to offer a new, 100-seat aircraft to the airlines. Boeing cites long lead time problems with both re-engined and mixer modified aircraft. This question will undoubtedly be addressed by industry in its response to the ANPRM.

- Potential Economic Impacts - The Stage 3 requirement for JT8D aircraft has potential adverse economic consequences on aircraft and engine producers as well as on small/medium sized communities. These impacts have not been quantified in detail in this study, but may represent an important regulatory consideration.

REPORT ORGANIZATION

Chapter 2 discusses the analytical methods applied to this problem while Chapter 3 presents study results. Appendix A shows individual airport data for the more than 100 medium and small airports analyzed to assess the 100-seat aircraft problem.

CHAPTER 2

STUDY APPROACH

OVERVIEW

A relatively straightforward approach to measuring costs and benefits associated with the proposed change in noise regulations was taken. The first step in the analysis was to identify candidate aircraft currently in production which meet Stage 2 noise limits, but not Stage 3 limits. This process is more complex than it appears at first glance because there are a large number of airframe and engine combinations possible for each type of aircraft (e.g., 747). Not all models offered have been produced and certified (the A-300 with RB-211 engines or the 707 with CFM-56 engines) so that data on noise levels -- either estimated or actual -- are not always available.

Because of the large number of airframe and engine combinations, either in production or possible, JWN has analyzed compliance problems by type of aircraft. JWN has not attempted to identify all of the models of a particular aircraft type that do not now meet Stage 3 limits. Those models actually analyzed are discussed more fully in Chapter 3, Study Results.

The potential in an unconstrained market for affected aircraft is the next important question. The potential market for wide body aircraft seems substantial through the late 1980s and into the 1990s.[1/] While increased costs associated with insuring that all wide body models meet Stage 3 limits after 1985 may shift an airline's preference from one aircraft to another, the requirement should not by itself act to truncate potential demand.

The potential market (in the post-1985 time frame) for narrow body aircraft is more difficult to assess and has a more important influence on costs associated with the proposed regulatory change. The backlog of orders coupled with new bookings insure that current two- and three-engine narrow bodies (727,

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[1/] The present DC10 engine-wing mating problem has not been considered in this study. In theory, airlines will be free to choose the "next-best" wide body should a major design problem limit future sales of the DC-10.

737, DC9) will remain in quantity production well into the 1980s. Two new Stage 3 narrow body aircraft[2/] (757 and DC9-80) are in development. Both are, however, larger and more costly (on a per-aircraft-mile basis) than current production two-engine aircraft. For this reason, JWN has examined both the route structures flown by these aircraft and the cities served in order to estimate: (1) the future requirement for small, short/medium range transports, and (2) the number of new production aircraft that would be required in the post-1985 period.

The next step in the analysis was to identify the potential technology fixes that would enable current production aircraft to meet Stage 3 or, alternatively, some point less than Stage 3 but representing a substantial reduction in noise. The increase in price resulting from the cost of developing and producing modified aircraft was estimated and combined with operating cost changes to obtain both seat-mile and aircraft-mile costs for the aircraft.

The first step, in the benefit analysis, was to develop (before and after modification) single event contours for each aircraft. Both 90 and 100 EPNdB contours were estimated because some technology fixes change in effectiveness with changes in the distance from the aircraft.

Area reduction is only one measure of benefit, and one that could be misleading. Industry claims, with justification, that the community impact of the proposed change will be very small and perhaps not commensurate with the cost. JWN has, therefore, conducted sensitivity analyses to illustrate community impacts and has estimated how many operations can be added to a given mix without degrading the noise environment.

Costs and benefits were then combined and the significant issues associated with the proposed regulation are discussed.

[2/] Estimated noise levels indicate that the DC9-80 will marginally meet Stage 3 limits. Douglas is confident that the aircraft can be so certified.

MARKET ANALYSIS

The market analysis was completed to evaluate two major questions: (1) the need for small, short/medium haul transports in the post-1985 period, and (2) if a need continues to exist, an estimate of the number of new aircraft the airlines would require. For the purposes of this analysis, small, short/medium range transports are defined to include 727 and smaller aircraft.

There are more than 400 communities in the U.S. that receive scheduled airline service and others that receive commuter service.[3/] In terms of volume, the airports serving these communities range from very large (millions of passengers per year and thousands of operations per day) like O'Hare or Atlanta, to very small (less than 10 operations per day with only a few thousand passengers per year). JWN examined CAB and FAA data[4/] on departures and enplanements to develop methods for analyzing this wide variety of airports. Airports were stratified into four categories and the number of departures by each type of aircraft at each airport were tabulated. The classes of airports and number of airports in each class for 1978 were as follows:

Categories	Number of Airports
1. 250 or More Air Carrier Departures/Day	12
2. 50 to 249 Air Carrier Departures/Day	43
3. 20 to 49 Air Carrier Departures/Day	55
4. 5 to 19 Air Carrier Departures/Day	130

There were at least 140 airports in the 48 contiguous states that had less than five departures per day. These and airports with only commuter service were not analyzed in detail.

3/ Airlines, in this discussion, include trunks, local service, and former intrastate carriers. Other carriers flying commuter-type aircraft are considered commuters.

4/ Sources included "Airport Activity Statistics" for 12 months ending September 1978, "Tower Airport Statistics Handbook," and "Terminal Area Forecasts".

Departures by generic class of aircraft were recorded for each airport in each category. The generic classes included:

4-Engine Wide Body (4 EWB)	747 Series
3-Engine Wide Body (3 EWB)	DC10, L-1011
2-Engine Wide Body (2 EWB)	A-300
4-Engine Regular Body (4 ERB)	DC8, 707
3-Engine Regular Body (3 ERB)	727 series
2-Engine Regular Body (2 ERB)	DC9, 737, BAC-111
Heavy Turboprop (HTP)	L-188
Light Turboprop (LTP)	CV-580, YS-11, F/FH-27/227, DHC DASH 7

Control totals for aircraft departures are available from the CAB statistics. The number of departures from airports not included in the categories listed above were verified. This allowed the percentage of total departures by each generic class of aircraft at each class of airport to be computed with a high degree of accuracy.

A review of these tabulations shows that airports in Categories 3 and 4 were served almost exclusively by 3 ERB or 2 ERB aircraft. A sample of more than 100 airports (shown in Appendix A) was drawn from these categories for further analysis.

Counting the number of airports served is only one step in determining future requirements for smaller transport aircraft. Stage lengths flown is a second important factor. JWN, therefore, selected a sample of airports and examined all scheduled flights operating at each to determine flight itineraries and stage lengths flown. The sample was drawn from the Official Airline Guide for August 1978 and included both large and small airports.

The method used was as follows:

1. Select a set of airports in a random fashion but which are representative of both geography and serving airlines.
2. Record the flight number, flight frequency, and type of aircraft used for each arrival at the airport.
3. Determine the flight itinerary for each flight recorded.
4. Determine the stage length flown for each city-pair in the flight itinerary.
5. Tabulate the stage lengths flown by each aircraft type and plot frequency diagrams for each.
6. Compare average stage lengths recorded for each aircraft type with CAB averages for the year.

This procedure was completed for the following aircraft types: 727-100, 727-200, 737, BAC-111, DC9-10, DC9-30 and DC9-50.

The last step in the market analysis was to assemble and rationalize the best available estimates of the unconstrained, post-1985 market for new production small transport aircraft. JWN assembled estimates prepared by airframe and engine producers, industry associations, and government agencies. Some were direct estimates of aircraft deliveries, and some were fleet projections. Where practical, JWN adjusted fleet projections by estimated retirements to obtain net additions to the fleet.

POTENTIAL TECHNOLOGY FIXES

Several technological approaches to reducing individual aircraft noise emissions were examined, the most viable of which included: (1) treatment of engines with sound absorbant material, (2) modifications to airframes to reduce required thrust on approach and provide greater altitude or reduced thrust at the FAR 36 takeoff measuring point, (3) aircraft modification to

accept new high bypass ratio engines, and (4) modification of engines and airframes to accept exhaust mixers with lobe suppressors. Engine and airframe manufacturers were consulted to determine the technological feasibility, cost and effectiveness of each approach for each candidate aircraft.

The Boeing Corporation has revealed several aircraft modifications to the 727 and 737 models which would meet Stage 3 with high bypass ratio engines, including a 2-engined version of the 727. However, such applications result in thrust-to-weight ratios and changes in weight distribution which necessitate airframe stretching to meet required operating cost criteria. This, in turn, has resulted in an aircraft size in which the airlines have demonstrated very little interest, and which, in one case, precipitates a 727 large enough to compete with the programmed Boeing 757 series. High bypass ratio engines are not available in a size range which would make the re-engining of the 727 possible without significant growth of the airframe. A "minimum modification" version of the 737 is feasible, but not economically attractive.

Boeing indicated that the jet exhaust mixer is a fairly well-developed technology with flight testing in progress for the 737.

Although Stage 3 probably cannot be met by the JT8D-powered aircraft with the mixer, significant reductions are possible. Because the mixer has its greatest effect on the jet-noise-dominated end of the emission spectrum, the inlet-turbine component is more significant. Since the higher pitched turbine noise is absorbed more efficiently in air than jet noise, the mixer technology results in noise reductions which, at distances beyond 1500 feet from the aircraft, exceed the 2.5 EPNdB reductions estimated for the FAR 36 takeoff and sideline measuring points. This results in a lessening of community impact at distances not reflected at the FAR 36 measuring points. At least one foreign airline has demonstrated an interest in aircraft powered by JT8D engines with mixers, which appear to represent the most fully developed feasible noise suppression technology currently available for JT8D-powered aircraft.

The McDonnell Douglas Corporation indicated that no attempt would be made to bring the DC9-30 or -50 aircraft into compliance with Stage 3. Instead,

the company would develop a new aircraft, if sufficient demand exists in the future. Douglas did not indicate what course of action might be taken if some standard between Stage 2 and Stage 3 (2.X) were promulgated, but presumably a Stage 2.X could serve as an incentive to pursue the mixer technology at some cost threshold. Note that a standard half-way between Stage 2 and Stage 3 has been suggested. JWN has attempted to define the "best" modification possible between Stage 2 and 3, hence the designation 2.X.

The DC10-30 requires some attention in order to meet Stage 3, and Douglas has indicated that a combination of SAM (Sound Absorption Material) treatment and wing modification may be utilized. The wing modification would result in reduced thrust on approach, and slightly higher landing speeds, both of which would reduce noise at the FAR 36 approach measuring point. The improved lift-to-drag ratio would also be of some benefit at the takeoff measuring point, as cutback could be initiated at an earlier point in the takeoff profile. The SAM treatment would benefit only the approach certification values, and is a logical step in view of increases in the dominance of turbine noise with reduced thrust. The Douglas Corporation is confident that the DC10-30 can meet Stage 3.

The Lockheed Corporation will be unaffected by early implementation of Stage 3, as the current production of the L-1011 is certified to Stage 3 levels.

AIRCRAFT NOISE EMISSIONS CRITERIA AND METRICS

The effect of early implementation of Stage 3 has been assessed using the Effective Perceived Noise Level (EPNL expressed in EPNdB) metric, primarily because FAR 36 specified the use of EPNdB for certification, but other advantages exist:

1. A review of sound level versus distance curves currently in use by the FAA, EPA and airframe manufacturers reveals closer agreement between EPNL data for specific aircraft than for the Noise Exposure Level (NEL) and Sound Exposure Level (SEL) metrics which are A-weighted. The greatest differences in sound level versus distance curves existed between JT8D-powered aircraft when measured by the A-weighted metrics.

2. The EPNdB data base is substantially derived from actual time-integrated measurement of aircraft in flight at various distances, while some of the SEL data have been derived from maximum A-level observations and computer simulations which estimate the effect of time integration, and distance.

The EPNdB versus distance curves presently exercised by the FAA Integrated Noise Model (INM) were used as a reference for each aircraft subjected to noise impact analysis. In some instances, where the noise data in the model did not represent the exact model of aircraft analyzed, data from other sources[5/] were used to modify the INM. This was especially important in the analysis of the mixer technology, because of changes in the slope of the sound level curves for the JT8D-powered aircraft, and for the DC10-30, because of changes in the sound level curves expected to result from the additional SAM treatment of the CF6-50 series engines.

Some sound suppression techniques do not generally alter the composition of the noise signature in a given aircraft. Examples include minor changes in required thrust resulting from wing modification changes in velocity, and, generally speaking, substitutions between engines with high bypass ratios. For this reason, changes in sound pressure level at one reference distance were assumed to occur equally at all points along the sound versus distance curves for technologies which were not likely to change the spectral content of the reference engine/aircraft combination.

CONTOUR ANALYSIS

Two EPNL contours were generated for each technical alternative to facilitate the assessment of community noise impact on a single event basis. Contour sound levels of 100 and 90 EPNdB were selected in order to reflect differences in impact occurring at points on the ground that are relatively close to the aircraft (100 EPNdB), and at greater distances where reductions in single event sound levels are potentially significant in the surrounding

[5/] U.S. EPA, Office of Noise Abatement. "Effective Perceived Noise Level Versus Distance Curves for Civil Aircraft." Technical Report By Bolt, Beranek & Newman, February 1976.

community (90 EPNdB). Changes in the respective contour areas were used to assess the relative effectiveness of alternative technologies.

The use of two contour levels is necessary because sound levels measured at the Part 36 measuring points are representative of community impact only at distances which are relatively close to an aircraft in flight (370 feet from aircraft on approach, and from 1000 - 1500 feet from aircraft on takeoff). Different sound-suppression techniques provide benefits which may increase or decrease substantially as the distance from the aircraft is increased. Since contour area is highly sensitive to changes in sound pressure level (a 1 db increase can increase area by 15-20%), two points of reference are necessary to give an accurate assessment of both the degree of benefit and the way in which the benefit changes as a function of increasing distance from the aircraft.

All noise contours were generated by the FAA Integrated Noise Model, using a single 10,000 foot runway, a standard 3^{0} approach and ATA takeoff profile specified in the model. Each aircraft analyzed made 100 landings and 100 takeoffs during the day period (0700 - 2200 hours) utilizing straight flight tracks of infinite length. The 100 and 90 EPNL contours were generated by requesting 32 NEF and 22 NEF, respectively.[6/]

The 100 aircraft movements (one takeoff, one landing) were necessary to eliminate the truncation of decimals by the model where operations were varied to reflect changes in EPNL resulting from the technical alternatives tested. In order to reflect changes in sound pressure level in the INM, the formula:

$$N = \frac{100}{10^{.1\Delta}}$$

was applied, where N is the number of takeoffs or landings and Δ is the change in EPNdB. Thus, if -3 EPNdB was obtained at takeoff thrust, and 0 EPNdB at landing thrust:

[6/] From the formula NEF = EPNL + 10 Log N - 88 where N is the number of operations.

$$N_t = \frac{100}{10^{.1(3.0)}} \quad \text{and } N_L = \frac{100}{10^{.1(0)}}$$

$$N_t = 50.1 \text{ takeoffs and } N_L = 100 \text{ Landings}$$

Thus, the INM could then be coded for 50.1 departures and 100 arrivals of the reference aircraft. Where the technology was not expected to change spectral content, both 32 and 22 NEF values could be requested, and the contours and areas generated could be regarded as representative. Where spectral content changed, it was necessary to code the INM twice: once for 100 EPNL and once for 90 EPNL, because Δ was different at each distance.

COST ANALYSIS

The goal of the cost analysis was to determine the change in aircraft operating costs (including depreciation of development and production cost increases) resulting from the application of noise-suppression technology. In theory, the following procedure could be applied to each technology:

1. Estimate the development cost of each technology application for each aircraft type involved.
2. Estimate incremental change in production costs.
3. Analyze impacts of the technology change on operating costs. In general, these will center on fuel consumption and could increase or decrease actual costs.
4. Estimate the potential number of aircraft sales. This will give the number of units over which development and production costs can be amortized.
5. Develop the incremental price increase required to recoup development and production costs and yield a reasonable return on investment.
6. Calculate resulting change in aircraft direct operating cost (including depreciation) and convert to cost-per-seat-mile and cost-per-aircraft mile.

The procedure could not, unfortunately, be applied to many of the important options open to the producers. Boeing, for example, has announced consideration of a two-engine version of the 727 which would meet Stage 3 noise limits. The company has, however, declined to reveal publicly just which engines are under consideration and regards its studies to date as preliminary and proprietary at this time. Similarly, Boeing has studied two re-engined versions of the 737 -- a minimum modification utilizing the JT8D-209 and a more significant modification using a clipped fan version of the CFM-56. The com- pany views neither as competitively attractive and regards potential costs and configurations as proprietary.

Douglas recognizes problems with the DC10-30 and believes they can be solved with a combination of aerodynamic and nacelle changes. The exact nature of the changes has not been determined and considerable analysis would be required to estimate near optimum combinations. Thus, Douglas was unable to supply sufficient information to support a reasonable estimate of potential costs.

The lack of specific cost information could be overcome, provided reasonable estimates of weight changes and other changes in aircraft characteristics were made available. These data would permit use of various airframe and aircraft cost estimating models which relate development and production cost of aircraft to such design parameters as weight, speed and range. Estimates of the price increment associated with re-engining can be based on an analogy to the DC8/CFM-56 program, but the modifications required on the aircraft of interest are much different and perhaps more extensive than those required for the DC8.

Where practical, analog methods were used. In other cases, costs were treated parametrically to identify the maximum allowable change in per mile or per-seat-mile costs which would allow the modified aircraft to remain competitive.

COMMUNITY IMPACTS

The use of the INM for the single event contour area analyses greatly facilitated the assessment of the composite effects of multiple aircraft operations at airports of different sizes on the surrounding community. The selection of the EPNL single event metric dictated the use of the Noise Exposure Forecast (NEF) metric for the community impact assessment.

Previous work conducted by JWN for the CAB using the INM has demonstrated that the growth of the 30 NEF contour area may be accurately predicted from the change in sound pressure level (NEF expressed in decibels), with R^2s in excess of .9996 for airports ranging in size from 10 to over 500 operations per day.[9/] This methodology may also be applied to the assessment of changes in 30 NEF area likely to result from changes in emissions in particular types of aircraft.

The 30 NEF analysis was designed as a direct output of the single event 100 and 90 EPNL INM contour runs. In addition to the required 22 (90 EPNL) and 32 (100 EPNL) NEF contours, values of 17, 27, and 37 NEF were specified as INM outputs, yielding values of 85, 90, 95, 100 and 105 EPNL which, for the specified 100 aircraft movements, also equaled 17, 22, 27, 32, and 37 NEF. This provided contour area as a function of NEF at five points, in 5dB increments, for each aircraft analyzed. Subsequent regression analyses indicated that a log-log relationship existed between NEF value and contour area. Each relationship was aircraft specific, and revealed significant predictive merit (the poorest R^2 obtained was .9980) for 30 NEF contour areas which ranged in the extreme case from less than 2.5 square miles to over 110 square miles. Holding the contour value constant at 30 NEF converted the NEF values along the ordinate into the number of aircraft movements necessary to generate a given 30 NEF contour area, for each of the five EPNL values:

9/ Civil Aeronautics Board. "Environmental Impact of Multiple Permissive Entry." Report by J. Watson Noah, Inc., April 1979.

EPNL	30 NEF MOVEMENTS
85	1995.26
90	630.96
95	199.53
100	63.10
105	19.95

The final result was a log-log relationship between aircraft movements and 30 NEF contour area for each aircraft type (See example, Figure 1).

This facilitates the comparison of different aircraft on an "Area Equivalent Operations" basis: the number of aircraft movements of each type of aircraft which are necessary to generate a specified 30 NEF contour area may be read directly from a graph, or calculated from regression equations. For example, Figure 2 reveals that at a small airport, about 5.2 727-200 aircraft movements would generate a five square mile 30 NEF contour, but an "equivalent impact" would require about 20.5 737 movements. In other words, about 3.9 737 movements equal one 727 movement for an impact area of five square miles. At 15 and 50 square miles, which represent, successively, larger airports, this ratio increases to about 5.4 to one and 7.5 to one, respectively. This is because the slopes of the regression lines reflect both aircraft performance (takeoff climb gradient and velocity) and the rate of atmospheric absorption of aircraft with different spectral compositions. The DC8-63 aircraft, powered by JT3D engines, has a significantly greater impact than the 727 at five square miles, but the impact of the DC8-63 and the 727-200 is equal at 60 square miles.

Similar analyses conducted for new technology aircraft resulting from early implementation of Stage 3 of FAR Part 36 result in area equivalencies for new aircraft which may be used to estimate 30 NEF impact at airports of various sizes. Such an approach has two important advantages: (1) benefit may be stated as the number of additional aircraft movements which may occur <u>without</u> increasing impact area, facilitating economic analyses based on aircraft activity, while (2) a measure of both decibel and impact area benefit is obtained where equivalent aircraft movements are permitted to vary.

FIGURE 1.

30 NEF AREA VS. MOVEMENTS
FOR 727, 737 AND DC8

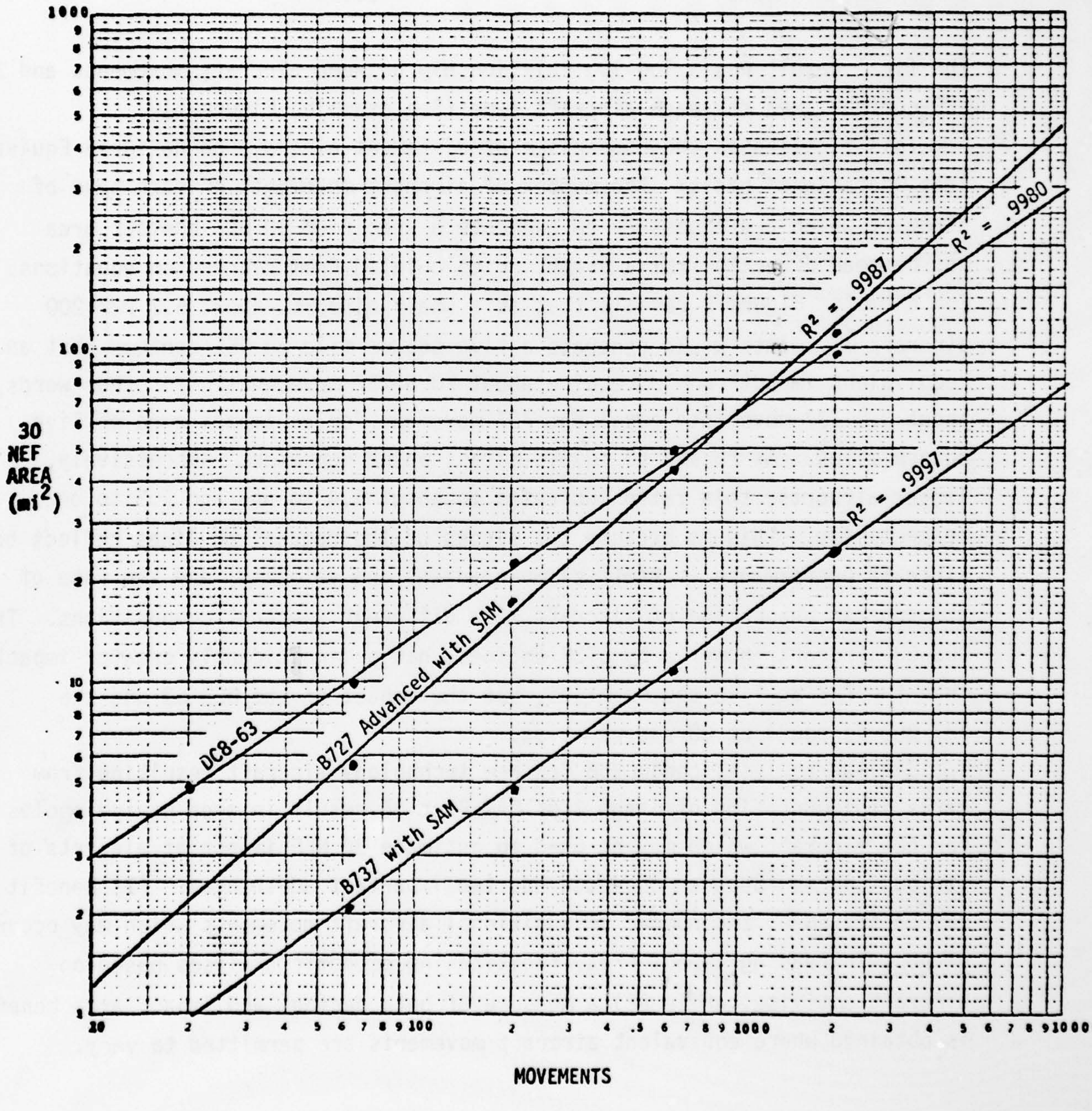
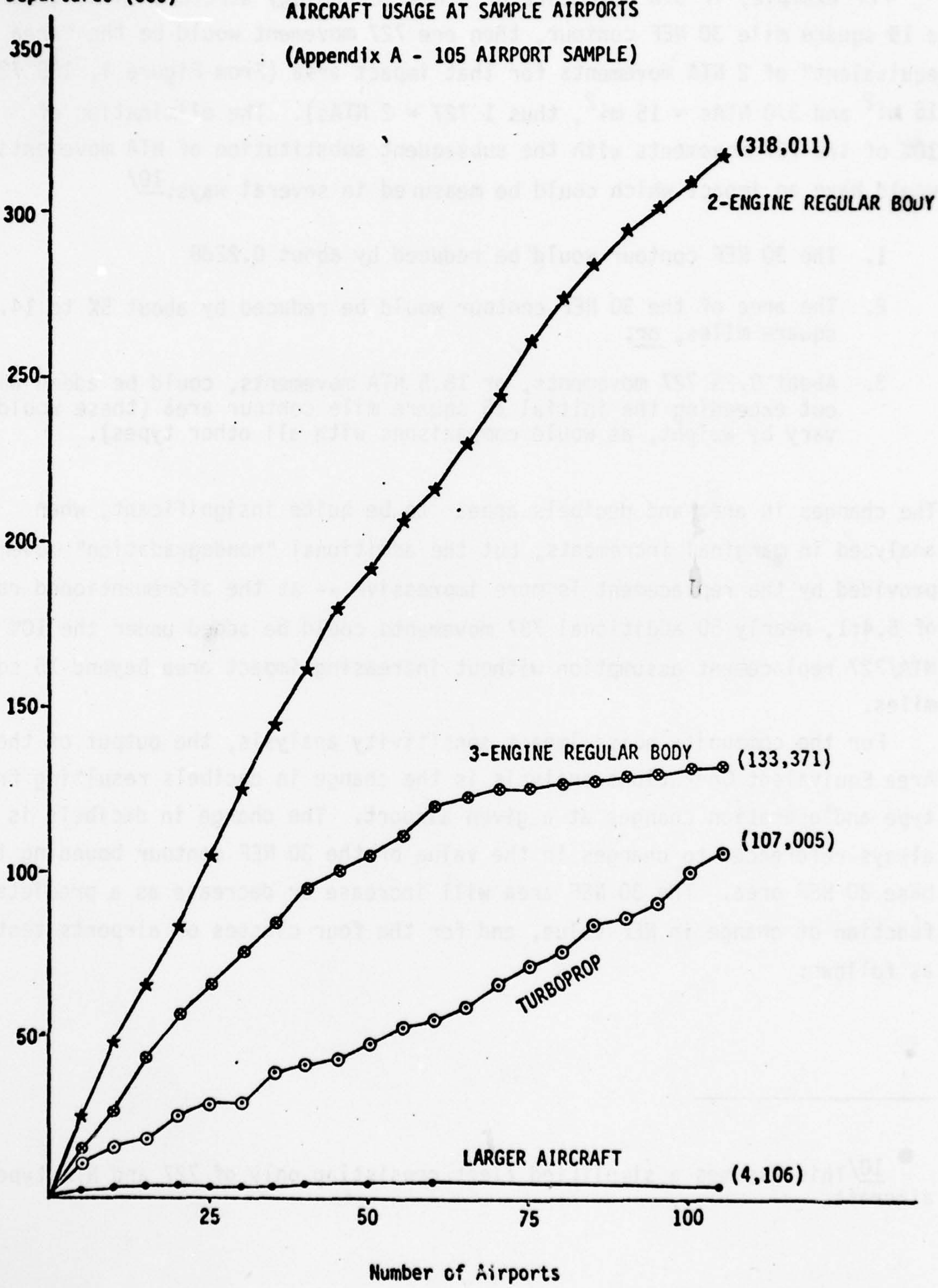


FIGURE 2

AIRCRAFT USAGE AT SAMPLE AIRPORTS

(Appendix A - 105 AIRPORT SAMPLE)



For example, if 370 movements of a new technology aircraft (NTA) generated a 15 square mile 30 NEF contour, then one 727 movement would be the "area equivalent" of 2 NTA movements for that impact area (From Figure 1, 185 727s = 15 mi^2 and 370 NTAs = 15 mi^2, thus 1 727 = 2 NTAs). The elimination of 10% of the 727 movements with the subsequent substitution of NTA movements would have an impact which could be measured in several ways:[10/]

1. The 30 NEF contour would be reduced by about 0.22dB
2. The area of the 30 NEF contour would be reduced by about 5% to 14.27 square miles, or;
3. About 9.25 727 movements, or 18.5 NTA movements, could be added without exceeding the initial 15 square mile contour area (these would vary by weight, as would comparisons with all other types).

The changes in area and decibels appear to be quite insignificant, when analyzed in marginal increments, but the additional "nondegradation" movements provided by the replacement is more impressive -- at the aforementioned ratio of 5.4:1, nearly 50 additional 737 movements could be added under the 10% NTA/727 replacement assumption without increasing impact area beyond 15 square miles.

For the community noise impact sensitivity analysis, the output of the Area Equivalent Operations analysis is the change in decibels resulting from type and operation changes at a given airport. The change in decibels is always referenced to changes in the value of the 30 NEF contour bounding the base 30 NEF area. The 30 NEF area will increase or decrease as a predictable function of change in NEF value, and for the four classes of airports tested, as follows:

10/ This assumes a simplified fleet consisting only of 727 and NTA type aircraft.

(1) Class 1: Log Area = 4.24969-0.08246*NEF (R^2 = 0.9997)

(2) Class 2: Log Area = 3.68314-0.08058*NEF (R^2 = 0.9999)

(3) Class 3: Log Area = 3.32020-0.08376*NEF (R^2 = 0.9999)

(4) Class 4: Log Area = 2.5680-0.07723*NEF (R^2 = 0.9999)

A 1.0dB decrease in NEF is always represented by a 1.0dB increase in the formula, because area decreases for higher values of NEF, i.e., the 31 NEF contour is inside of the 30 NEF contour (the R^2s apply to changes occurring between 28 and 34 NEF).

The task of aircraft noise suppression is ultimately one of providing small incremental gains where new technology aircraft gradually replace older types. However, degradation of the noise environment is also incremental, and the objective becomes one of continuously providing incremental improvements which more than offset incremental degradations. The fact that the average individual cannot perceive each increment is not as important as the overall trend that is established in the noise environment.

For this reason, study results concerning community noise impact are presented utilizing the three criteria, above, (1) change in the average NEF value occurring along the 30 NEF contour, (2) change in 30 NEF contour area, and (3) change in the number of equivalent aircraft movements which may be added without increasing 30 NEF contour area.

CHAPTER 3

STUDY RESULTS

This Chapter presents the results obtained by applying the methods discussed in Chapter 2. In addition, several issues regarding the regulation as advanced by producers are presented and discussed.

CANDIDATE AIRCRAFT

Early implementation of Stage 3 will impact upon current production aircraft meeting Stage 2 which do not meet Stage 3, including the 727, 737 and DC9 aircraft powered by JT8D series engines, the DC10-30, powered by CF6-50 engines and several models of the 747. The consideration of some Part 36 requirements falling between Stage 2 and Stage 3 results in a modified list of potentially non-complying aircraft, especially when new technology fixes are applied.

The wide bodied DC10-30 and 747 aircraft have the least difficulty complying with Stage 3 levels. Boeing indicates that available technology permits them to qualify all 747s "on paper," but a substantial problem concerning the statistical probability of certification during actual flight tests exists, as discussed below. The DC10-30 is 2.8dB over Stage 3 limits at takeoff, 4.1dB under at sideline, and 3.7dB over at approach measuring points (for 565,000 pounds). This amounts to a 2.4dB excess overall, but tradeoff limitations require a total decrease of 3.5dB (0.8dB for takeoff, and 2.7dB for approach) to avoid exceeding 2.0dB at any point, or 3.0dB overall. Presumably, the approach requirement is controlling, as both SAM treatment and wing modification are necessary to obtain a 2.7dB reduction. This should improve takeoff performance sufficiently to obtain the necessary 0.8dB on takeoff.

The 737, 727 and DC9 aircraft are substantially over Stage 3 levels at takeoff and sideline (see Table 1) and cannot meet Stage 3 without re-engining. However, significant reductions in noise are possible with the mixer. At the FAR 36 measuring points, this amounts to approximately 2.5dB for takeoff and sideline and 0dB on approach, indicating that FAR 36 levels midway between Stage 2 and Stage 3 could be met.

Stage 3 can be met by these aircraft by substituting high bypass ratio engines, which has been analyzed in detail at Boeing. However, the production of such aircraft is considered unlikely by Boeing because of substantially increased costs. Therefore, much of the potential noise reduction resulting from early implementation of Stage 3 is dependent upon the actual noise levels promulgated, and the effectiveness of the mixer technology.

THE "100-SEAT" AIRCRAFT PROBLEM

It appears that most wide body aircraft can be certified to Stage 3 levels, at least on paper. Potential problems with the "certainty" of noise reductions, the magnitude of reductions required compared to certification procedure tolerances and producer guarantees to customers are issues raised by producers that will be discussed later. From a purely technical point of view, it appears that only the DC10-30 faces substantial problems and Douglas believes these can be resolved.

The situation with regular body aircraft is quite different. The requirement for a small, short/medium range transport will continue through the 1990s. Table 2 shows the number of departures by type of aircraft from each class of airport defined in Chapter 2. The Table shows that more than 95% of all large aircraft departures (4 ERB or greater) occur at the 55 largest airports (Classes 1 and 2), but that 2 or 3 ERB aircraft predominate at the smaller airports.

Passenger enplanements help explain the indicated aircraft size-departure relationship. Average enplanements for an airport in each class were as follows:

TABLE 1

NOISE REDUCTION REQUIREMENTS [1/]

NOMINAL LEVEL REQUIREMENTS (NO ALLOWANCE FOR FLIGHT TEST) [2/]

	SIDELINE	CUTBACK	APPROACH	TOTAL
727	7	5	-1	11
737	8	5	1	14
DOMINANT COMPONENTS	JET	JET	INLET FAN	
	CORE	CORE		

1/ Source: Boeing Aircraft Corp.

2/ The DC9-50 requires 8 for takeoff, 6.5 for sideline and 2.4 for approach.

TABLE 2

DEPARTURES BY TYPE FROM EACH AIRPORT CLASS
12 MONTHS ENDING 30 SEPTEMBER 1978
(Thousands)

AIRPORT CLASS	TOTAL	4 EWB	3 EWB	2 EWB	4 ERB	3 ERB	2 ERB	2 ETP
Class 1 & 2	3,437.8	48.3	229.8	4.3	335.9	1,467.6	1,084.3	267.6
Class 3	565.2	0.2	3.0	0.4	10.4	223.2	269.5	58.5
Class 4	458.4	0.0	0.5	0.0	3.3	74.4	249.2	131.0
All other	123.9	0.0	0.0	0.0	0.0	3.5	37.4	83.0
TOTAL	4,585.3	48.5	233.3	4.7	349.6	1,768.7	1,640.4	540.1
PERCENT OF TOTAL								
Class 1 & 2	75.0%	99.6%	98.5%	91.3%	96.1%	83.0%	66.1%	49.5%
Class 3	12.3	0.4	1.3	8.7	3.0	12.6	16.4	10.8
Class 4	10.0	0.0	0.2	0.0	0.9	4.2	15.2	24.3
All other	2.7	0.0	0.0	0.0	0.0	0.2	2.3	15.4
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

NOTE: CAB certificated carriers only.

Class 1 & 2	-	3,592,000	enplanements
Class 3	-	405,000	enplanements
Class 4	-	123,000	enplanements
All others	-	25,000	enplanements

In total, domestic trunk airlines carried 80% of the passengers, local service airlines about 20%. Such newly certificated, former commuter airlines as Air New England and Air Midwest are excluded, along with special carriers like Aspen, Wright and New York Airways.

About 83% of enplanements (for certificated carriers) occurred at Class 1 and 2 airports while the remaining 17% were spread among the 55 Class 3 airports (9%), 130 Class 4 airports (7%) and 140 other airports (1%). Table 3 shows enplanements by carrier type and airport class for 1978. Trunk airlines board more than 87% of these passengers at Class 1 airports as compared to 65% for local service airlines. Conversely, the locals derive more than 20% of the business from the 270 smaller airports as opposed to about 7.5% for trunks.

The relationship between departures, passengers and size of aircraft can be better understood from the information in Table 4 which shows passengers and seats per departure by class of airport along with the average number of seats for each aircraft type. The table shows that many of the other airports (which average only 2.4 departures and 41 passengers per day) can be efficiently served by commuter airlines with little degradation in quality of service. Many of the airports are presently served by commuters.

Appendix A contains data on a sample of more than 100 smaller airports ranging from 2,250 to 14,500 departures and from 60,000 to 380,000 enplanements. Of the 105 airports, 10 receive trunk service only, 33 receive local service only and 62 are served by both. Trunks serve 24 of the 25 airports with 250,000 or more passengers, but of the 53 airports with less than 150,000 passengers, trunks serve only 23. Overall, trunk airlines carried 54% of the passengers, but 70% of this total came from the top 25 airports.

TABLE 3

ENPLANEMENTS BY CARRIER TYPE AND AIRPORT CLASS

1978

	ENPLANEMENTS (000)			PERCENT OF AIRPORT TOTAL		PERCENT OF CARRIER TOTAL	
	TOTAL	TRUNKS	LOCAL	TRUNKS	LOCAL	TRUNKS	LOCAL
Class 2	3,592	3,021	571	84.1%	15.9%	87.6%	65.0%
Class 3	405	279	126	68.9	31.1	8.1	14.4
Class 4	123	60	63	48.6	51.4	4.1	16.9
Other	15	3	12	17.4	82.6	0.2	3.7

TABLE 4

PASSENGER AND SEAT DATA BY AIRPORT CLASS
1978

	AVERAGE ALL AIRPORTS	CLASS 1 & 2	CLASS 3	CLASS 4	ALL OTHERS
Departures per Day	33.06	171.2	28.15	9.66	2.42
Passengers per Day	1,716	9,840	1,110	337	41
Passengers per Departure	51.90	57.50	39.40	34.90	17.0
Seats per Departure	112.3	119.6	98.70	84.80	64.6
Passengers per Seat	.462	.480	.399	.412	.263

AVERAGE SEATS BY AIRCRAFT TYPE

4 EWB	357 Seats	4 ERB	150 Seats
3 EWB	246 Seats	3 ERB	118 Seats
2 EWB	229 Seats	2 ERB	92 Seats
		2 ETP	50 Seats

Figure 2 shows cumulative aircraft departures against airports arrayed in descending order of enplanements. There are a few large aircraft departures for some of the airports. These include:

- Billings, Montana - 164 4 EWB, 143 3 EWB
- Great Falls, Montana - 3 4 EWB, 123 3 EWB, 78 4 ERB
- Mobile, Alabama - 1,415 4 ERB
- Daytona Beach, Florida - 386 3 EWB.

Large aircraft totalled less than 1% of all operations.

Two-ERB were the most numerous aircraft used at sample airports totalling 56% of all departures. Three-ERB aircraft total 23% of operations, but only a few of these operations were at airports with less than 150,000 passengers. The turboprops, which were 19% of the total, completed 36% of the departures at airports with less than 100,000 passengers.

Table 5 summarizes operations at the sample airports and illustrates that the carriers have matched aircraft and passengers quite consistently, except for small airports.

This analysis shows that air transportation service levels to medium and small communities is highly dependent on the availability of relatively small jet transports. Many of the airports, even with substantial growth, are unlikely to generate traffic sufficient to support the use of large aircraft. In addition, physical limitations may be important. Average runway lengths, based on a 100% sample of airports by class provided by the FAA Airport Information File, are as follows:

- Class 1 & 2 - 9,200 feet
- Class 3 - 7,900 feet
- Class 4 - 6,650 feet
- Other - 6,350 feet

TABLE 5

OPERATIONS SUMMARY FOR SAMPLE AIRPORTS

RANGE OF PASSENGERS (000)	NUMBER OF AIRPORTS	PASSENGERS PER DEPARTURE	SEATS PER DEPARTURE	PASSENGERS PER SEAT
350 or More	2	28.3	84.3	.34
300 - 349	11	40.5	98.0	.41
250 - 299	12	35.0	93.8	.37
200 - 249	13	34.6	92.2	.38
150 - 199	14	32.0	93.8	.34
100 - 149	26	29.4	86.9	.34
61 - 99	27	22.4	78.8	.28
AVERAGE		32.0	90.0	.36

FAA takeoff field lengths for various large aircraft are:

- 747-100 - 9,000 feet
- 747 SP - 7,800 feet
- DC10-10 - 9,000 feet
- DC10-30 - 10,500 feet
- L-1011 - 7,980 feet
- DC8-61 - 10,000 feet
- 707-300 - 10,000 feet

which indicates that large aircraft could not operate (fully loaded) from many of the airports.

If present trends continue, service to small airports may become more difficult to provide. Local service airlines are phasing out turboprop aircraft with a high retirement rate. Their fleet contained 142 2 ETP aircraft at the end of 1977, but only 88 at the end of 1978. A recent fleet projection for 1981 prepared by the CAB estimates only 40 turboprop aircraft would be in service by the end of 1981.

Commuter airlines are, however, procuring both new (F-27 and DHC Dash 7) and used turboprop aircraft. Moreover, a recent CAB decision concerning a replacement carrier for Delta at Presque Isle, Maine, specified the use of a 40-seat turboprop by the new carrier. While JWN does not believe that the light turboprop can compete with the small jet transport on many routes, such aircraft may well have lower per mile costs than the larger jet transports. Nevertheless, it appears probable that many small communities will lose service by trunk and local service carriers.

<u>Stage Lengths Flown by Small/Medium Transports</u>

The discussion above centers on the types of airports which tend to be dependent on smaller transport aircraft. The next step is to examine the stage lengths flown (miles between landings) by aircraft of these types.

Tables 6 and 7 show a breakdown of stage lengths flown by the aircraft of interest. The data were obtained from the sample drawn from the Official Airline Guide as discussed in Chapter 2. Almost 60% of all 2 ERB flights were of less than 300 miles, averaging about 160 miles. Some of the city pairs of less than 300 miles are high density routes capable of supporting wide body aircraft as they become available in quantity. New York to Washington or Boston, Dallas to Houston, and Chicago to Detroit are good examples. Others of these short stage lengths are relatively low density routes -- Piedmont Flight 68, for example, is a 737 operating over the following route: Norfolk, Richmond, Roanoke and Pittsburgh.

The distribution of stage lengths flown by 2 ERB aircraft is definitely skewed by the preponderance of short stage lengths -- the average stage length is greater than the median and modal value. The distribution of 3 ERB stage lengths is relatively uniform up through 800 miles, which illustrates the versatility of the aircraft.

Deregulation should lead to a more uniform distribution of stage lengths for 2 ERB aircraft. The local service airlines have taken advantage of the relaxed market entry regulations and have added city pairs that offer both traffic density improvements and stage lengths better suited to the aircraft. Nevertheless, continued service to medium/small communities probably means that aircraft capable of economically flying relatively short and low density stage lengths will be required.

Post-1985 Market

It is certain that the JT8D-powered aircraft will be operating in large numbers during the last half of the 1980s and well into the 1990s. Orders already on hand insure that quantity production of these aircraft will continue into the early 1980s. It is not clear that the demand for new aircraft of these types can be sustained into the post-1985 time period.

The existing fleet as of 31 December 1978 is shown in Table 8. These aircraft make up a substantial portion of the total airline fleet and will carry

TABLE 6

BREAKDOWN OF STAGE LENGTHS FLOWN
TWO-ENGINE REGULAR BODY AIRCRAFT
YEAR 1977

STAGE LENGTH (MILES)	PERCENT OF TOTAL FLIGHTS TOTAL DOMESTIC	TRUNKS	LOCAL SERVICE	AVERAGE TRIP TOTAL DOMESTIC	TRUNKS	LOCAL SERVICE
0 - 99	14.5%	12.8%	15.9%	73	75	71
100 - 199	26.3	19.8	31.8	144	146	142
200 - 299	17.7	14.1	20.8	256	259	254
300 - 399	17.4	20.2	15.0	346	357	336
400 - 499	10.7	12.2	9.5	452	468	438
500 - 599	8.6	13.1	4.8	569	578	561
600 - 699	1.7	2.8	0.8	645	681	614
700 - 799	1.9	3.5	0.5	777	793	764
800 - 899	0.6	1.3	0.0	866	866	0
900 - 999	0.1	0.0	0.1	987	0	987
1000 and more	0.5	0.2	0.8	1034	1018	1047
	100.0%	100.0%	100.0%	289	340	246

TABLE 7

BREAKDOWN OF STAGE LENGTHS

727 - 100/200 AIRCRAFT

YEAR 1977

STAGE LENGTH (MILES)	PERCENT OF TOTAL IN GROUP	PERCENT OF TOTAL CUMULATIVE	AVERAGE MILES IN GROUP	AVERAGE MILES CUMULATIVE
0 - 99	7.1%	7.1%	70	70
100 - 199	10.6	17.7	149	117
200 - 299	10.5	28.2	240	163
300 - 399	12.0	40.2	343	217
400 - 499	8.7	48.9	447	258
500 - 599	11.8	60.7	541	313
600 - 699	9.0	69.7	639	355
700 - 799	11.6	81.3	742	410
800 - 899	5.6	86.9	838	438
900 - 999	4.7	91.6	934	464
1000 - 1500	7.3	98.9	1227	520
1500 and More	1.1	100.0	1572	532

TABLE 8

SMALL/MEDIUM JET TRANSPORT FLEET
31 DECEMBER 1978

	3-ENGINE	2-ENGINE			
	727	737	DC9	BAC-III	TOTAL
TRUNKS	863	81	146	0	227
LOCAL SERVICE	14	49	209	30	288
INTRASTATE	32	22	5	0	27
ALASKA/HAWAII	10	15	9	0	24
TOTAL	919	167	369	30	566

SOURCE: World Aviation Directory, Summer 1979

a significant portion of total passengers well into the future. An unpublished CAB projection, for example, estimated that these small and medium aircraft would deliver 46% of total passenger miles in 1981.

The Air Transport Association (ATA) furnished JWN a fleet projection through 1985 based on a June 1978 survey of its members. The ATA fleet excludes the intrastate carriers shown above, but includes both Air Canada and CP Air. The ATA projection is shown in Table 9, while Table 10 shows additions to and retirements from the ATA for the years covered (1979-85).

The ATA projection forecasts the addition of 12 to 15 new small/medium aircraft each year for 1982 to 1985. A survey of 59 North American and Caribbean Airlines, conducted by Douglas Aircraft and furnished to JWN, indicates a potential market of 8-10 aircraft of this type per year after 1985, excluding the DC9-80. The same survey indicated a market average of about 85 aircraft per year for new technology, short/medium range aircraft including the DC9-80. Boeing, in a more recent projection, estimates a potential market for some 164 aircraft between 1985 and 1990, an average of 27 aircraft per year.

All of the estimates indicate that there will be a continuing but small market for new small transport aircraft of the JT8D-powered type -- perhaps 100 to 150 aircraft of all types. Even if one aircraft captured the entire market,
an unlikely event, the potential market provides only a small market for amortizing major modification costs.

Deregulation Effects, Potential Buyers, and Competitive Aircraft

Deregulation, with its increased competition and guarantees of service to small communities, will increase the need for smaller transports. If practice to date is an indication of future strategies, the smaller airlines will not attempt head-on competition with large entrenched carriers on high density routes. The local service carriers seem to be selecting new routes which are efficient in terms of aircraft utilization, but lower density, suitable for their JT8D-powered fleets. Non-Big Four trunks seem to be adopting spoke and

TABLE 9

ESTIMATED AIRCRAFT IN FLEET AT YEAR END

ATA MEMBERS ONLY

JUNE 1978 SURVEY

	1977	1978	1979	1980	1981	1982	1983	1984	1985
BAC-111	31	30	30	29	28	28	28	28	28
DC-9-10	82	81	80	80	80	80	80	80	80
DC-9-30	249	247	259	268	271	274	278	279	284
DC-9-50	34	42	48	48	51	53	55	55	55
DC-9-80	0	0	0	2	4	8	8	8	8
B-737-100	1	0	0	0	0	0	0	0	0
B-737-200	140	149	162	163	165	169	173	178	180
B-727-100	377	358	338	324	315	300	276	236	214
B-727-200	472	553	614	671	695	697	699	702	705

TABLE 10

RETIREMENTS AND ADDITIONS TO FLEET - ATA MEMBERS ONLY
JUNE 1978 SURVEY

	DC-9-10		DC-9-30		DC-9-50		B-737		B-727		TOTAL	
	RET	ADD	RET	ADD	RET	ADD	RET	ADD	RET	ADD	RET	ADD
1979	1	0	0	12	0	6	1	14	20	61	22	93
1980	0	0	1	10	0	0	1	2	14	57	16	69
1981	0	0	3	6	0	3	1	3	9	24	13	36
1982	0	0	0	3	0	2	1	5	15	2	16	12
1983	0	0	1	5	0	2	1	5	24	2	26	14
1984	0	0	3	4	0	0	3	8	40	3	46	15
1985	0	0	2	7	0	0	0	2	22	3	24	12
TOTAL	1	0	10	47	0	13	8	39	144	152	163	251

RET = Retirements

ADD = Additions

hub concepts which will serve as feeders to the already established, longer haul routes. JWN concludes from the growth in city-pair authority that deregulation will reinforce the future need for smaller transport aircraft.

U.S. producers have no plans at this time to produce either a new, 100-seat aircraft or new Stage 3 engines to power such an aircraft. The refanned JT8Ds are already too large for such an application in an optimum manner. The CFM-56, rated at 22,000 pounds thrust, is also too large and the clipped-fan version is not yet in full scale development. Overseas, Rolls-Royce is considering the RB-432 with a nominal thrust of 19,000 pounds. The company has not yet received authority for full scale development and at least a five year interim will be required before production.

There are several European built or derived small jet transports that are potentially available. These include the HS-146, Super F-28 (or F-29) and VFW-614. The HS-146, probably best configured for 60 to 80 passengers, is under development by British Aerospace. It is a high-wing, four-engined transport utilizing the AVCO-Lycoming AFL-502 engine rated at about 6000 pounds thrust. So far as we can determine, there is little U.S. interest in this aircraft at this time. The aircraft will probably meet Stage 3 limits.

The F-28 and the proposed F-29 are also less than 100-passenger aircraft. The F-28 utilizes the Rolls-Royce Spey engine and will not meet Stage 3 limits even though impressive work on quieting the aircraft has been done. The F-29, if built, will utilize the RB-432 or a similar Stage 3 engine. Since neither the engine nor the aircraft is in actual development, the F-29 is a doubtful alternative to current production aircraft.

Gulfstream American has acquired rights to the VFW-614 aircraft and is considering a re-engined version of the aircraft utilizing the GE-CF-34 engine. The exact configuration under consideration is undetermined, but the aircraft will be of similar size to the HS-146 and F-28.

It does not seem likely that any of these aircraft will be serious competition for the "100-seat" aircraft concept. There may be a market for such aircraft for carriers now in the regional-commuter carriers particularly

if a quality-of-service criteria is developed for replacement carriers. These small aircraft may, therefore, be more in competition with LTP aircraft rather than current production 2 ERB jet aircraft operated in the U.S.

The potential customers for a new technology, or, for that matter, a re-engined 100-seat aircraft, present an institutional barrier to program success. The European aircraft discussed above all received government assistance in the development phase. Normally, U.S. aircraft programs are launched only when enough orders are on hand to indicate program success. Historically, then, the initiation of new aircraft is highly dependent upon a large block order from one or two of the major carriers. The carriers who will use the small transports in the 1985 time frame do not have the financial resources to buy a large block of aircraft at one time. While not insurmountable, accumulating sufficient orders to undertake full scale production will be a problem for U.S. producers.

POTENTIAL COST-OF-COMPLIANCE

Reasonable estimates of costs-of-compliance are difficult to develop for some of the candidate aircraft. These include:

- 747 - certain models will require modification to meet Stage 3. In most cases, however, the cost and resulting performance penalties are expected to be small.
- DC10-30 - this aircraft will require extensive changes so that both cost increases and performance penalties will be significant.
- Re-engined 727 - Boeing has announced that it is studying this option but has released no details except the current JT8D-200 series engines are not under consideration. Near term options then are limited to the CFM-56 and clipped fan versions of the CF6 and RB211 since the JT10 and RB-432 are not yet in full scale development. Increased costs associated with this program make increased capacity attractive so that seat-mile costs of the resulting airplane remain competitive. Use of the larger engines would probably lead to an aircraft competing with the 757.
- Re-engined 737 - a minimum modification would involve utilizing the JT8D-209. Use of the CFM-56 (clipped fan) would require more extensive changes. Based on the DC9-80, it appears that a re-engined version of the 737 would require increased capacity to be competitive.

- Mixer applications - mixer applications are expected to increase the cost of a JT8D engine by approximately $80,000. Additional costs may be incurred because of aircraft peculiar installation prob- lems particularly for 727 applications. The $80,000 price includes amortization of producer funded development costs, field test, certification costs and production tooling as well as the incremental production cost increase associated with a mixer-engine combination.

The costs of modifying Stage 1 aircraft required under current legislation give some indication of the magnitude of the costs discussed above. Boeing supplied the following estimate of retrofit costs:

- Quiet Nacelles for 707 - $3.2 million/aircraft
- Quiet Nacelles for 727 - $175,000/aircraft
- Quiet Nacelles for 737 - $230,000/aircraft
- Re-engine 707/DC8 with CFM-56 - $11.0 million/aircraft

Note that the re-engine cost includes the engines, nacelles and any necessary aircraft modification. In addition to these costs, a one time cost of more than $1 million will be incurred for each type of aircraft requiring FAR 36 certification.

While accurate estimates are impossible, a 5% increase in 747 cost with a 2% fuel penalty translates to a 2 to 3% increase in per mile and per seat-mile costs. The cost for the DC10-30 will be substantially higher. In all cases, alternative wide body aircraft are available. Thus, airlines can trade off the increased cost of modified and other available models and select the best aircraft for their individual application. Considerably more information on the particular technology fixes required is needed before accurate cost estimates can be made.

Boeing does not believe that any of its re-engined narrow body aircraft are economically attractive. Because most of the design data is regarded as proprietary, JWN is not in a position to estimate actual costs. This leaves a major question to be answered: how attractive are the economies of the modified aircraft compared to other Stage 3 aircraft that are or will be available?

First, JWN does not believe that Boeing will market a 727 with "clipped fan" CF6 or RB211 engines. Economics dictate that such an aircraft would be very close to the 757 in capacity and would require major redesign. It would require using airlines to make a significant investment (perhaps 35% of total installed engine cost) for spare engines, engine spares and support equipment. In the end, the stretched 727 would have seat-mile and aircraft-mile costs that are not substantially different from the 757.

The economics of the CFM-56/727 and the re-engined 737s are more difficult to judge. JWN believes that the CFM-56/727 would be stretched somewhat to achieve lower seat-mile costs. The fuel savings, in the 5% range, would be somewhat offset by a significant increase in engine maintenance cost. Seat-mile costs therefore, would probably be in the range of current 727 costs, but per mile costs would be substantially greater.

The minimum modified 737 (JT8D-200 engines) would have an increased purchase price and operating costs somewhat greater than current models. Improved specific fuel consumption (SFC) would be offset by increased weight and increased engine maintenance. Similarly, the CFM-56 (clipped fan) 737 would cost more to buy and operate unless capacity were increased.

The following data, supplied by Boeing, but interpreted by JWN, illustrates the 100-seat aircraft dilemma. Figure 4 shows a cost comparison for aircraft that are or will be available in the early 1980s (note that the plot labeled "JT8D REFAN STRETCH" is representative of the DC9-80 and the 737-200 plot is representative of the DC9-30). The figure illustrates that the 2 ERB aircraft are preferred on low density routes where per mile costs are dominant. The annual cost penalties for flying a larger aircraft (assuming a fixed passenger load) are \$1.5 million for the JT8D REFAN and \$3.7 million for the 757.

The key question to be answered is where on Figure 3 the modified 2 ERB would have to fall for it to be a viable alternative if early implementation of Stage 3 eliminates current production aircraft in 1985. It appears that even with a substantial increase of, say, $1 per mile, a modified aircraft would be preferred for some routes. Since a $1 per mile increase equates to approximately $0.9 million in direct operating cost (DOC) for 2 ERB aircraft, a substantial aircraft price increment could be recovered through depreciation providing other elements of DOC did not increase substantially. The airlines would, of course, require a significant increase in short haul fares if they were to continue servicing these routes. Thus, although a modified aircraft might be preferred to any other existing model, it is not clear that it could be used by airlines without a fare increase.

Mixer equipped aircraft, on the other hand, will demonstrate lower noise levels at apparently modest increases in per mile and per seat-mile costs. JWN esti- mates that the annual increase in DOC will be approximately $40,000 for 3 ERB and $30,000 for 2 ERB or less than a 1% increase in per mile and per seat-mile costs.

POTENTIAL REDUCTIONS IN SINGLE EVENT CONTOUR AREA

The mixer technology was subjected to single event 90 and 100 EPNdB contour analysis using the INM, proprietary data provided by Boeing, and the noise curve compensation techniques discussed in Chapter 2. Contour area estimates are presented in Table 11. All comparisons are made with "current production" aircraft, but because several different engines are presently used on each aircraft type, and sound level versus distance data is somewhat inconsistent, the percent change in contour area is more representative of relative impact than are the predicted areas. Predicted areas may be slightly larger or smaller depending upon the series of JT8D engines in use (i.e., JT8D-15 versus JT8D-17), but the percent change in area will remain relatively constant for any comparison between particular versions of JT8D engines. All comparisons are between JT8D engines with quiet nacelles and JT8D engines with

FIGURE 3

COST COMPARISON - SHORT RANGE, SMALL AIRPLANE MARKET

- Total Airplane Costs including Capital
- Typical Mixed Class Seating

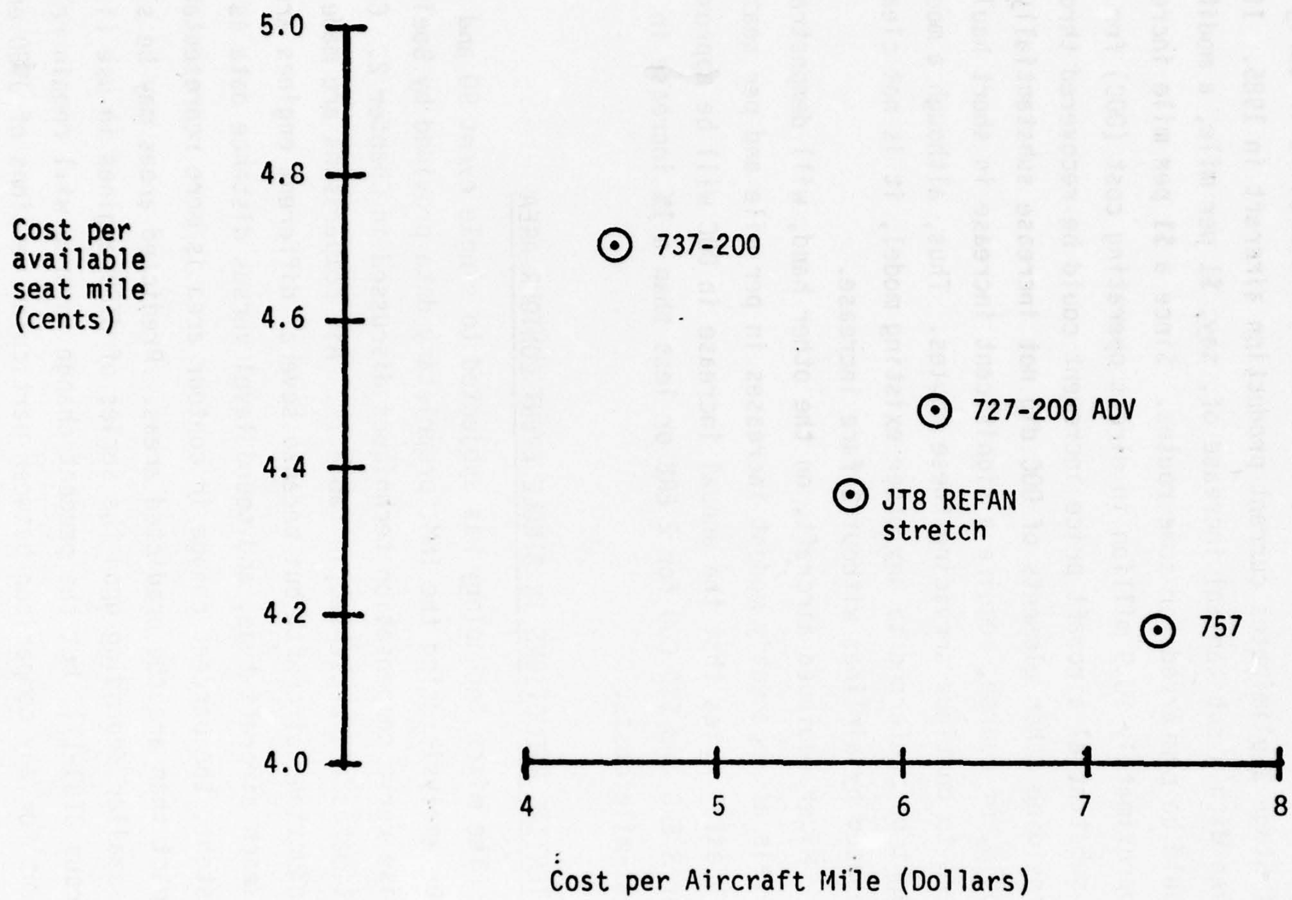


TABLE 11

90 AND 100 EPNdB

CONTOUR AREA FOR 727,737 AND DC9 AIRCRAFT

WITH AND WITHOUT MIXERS

TYPE	STAGE LENGTH	90 EPNL AREA (mi^2)			100 EPNL AREA (mi^2)		
	(nautical mi)	Base	New	% Change	Base	New	% Change
B737-200	0- 500	10.89	6.92	-36.5	2.18	1.64	-24.8
B727-200	500-1000	43.67	23.90	-45.3	5.68	3.17	-44.2
DC9- 50	0- 500	16.32	9.83	-39.8	2.93	2.17	-25.9

quiet nacelles plus mixer. Comparisons with JT8D engines without quiet nacelles were not made, since they do not meet Stage 2 limits. Figures 4 through 9 present the 90 and 100 EPNdB contours for the 737, DC9, and 727 with and without the mixer technology.

The reductions for all three types at 90 EPNdB (36 to 45%) and for the 727 at 100 EPNdB (44.2%) are significantly greater than expected from the indicated 2.5dB decrease at the critical certification points.

There are two reasons for this:

1. The mixer technology eliminates sound energy from the lower end of the frequency spectrum. Consequently, the sound levels emitted with mixer attenuate more rapidly in air than with SAM alone, resulting in a reduction in sound level which increases with distance.

2. Slightly greater reductions occur at intermediate thrust levels than at takeoff thrust, and the degree of cutback on takeoff, as well as the point at which cutback occurs, will affect the degree of benefit calculated for the mixer with SAM over SAM only.

The 25% reduction in area calculated for the DC9 and 737 at 100 EPNdB reflects sound level reductions in the 2.5dB range because the slant distance from the aircraft to the 100 EPNL contour is only about 1000 to 1500 feet. This distance is comparable to the distance which might be expected at the FAR 36 takeoff and sideline measuring points, and is consistent with estimates of a 2.5dB reduction at those points.

On a single event basis, the reductions provided by the mixer may be quite significant at points in the community currently impacted by 90 EPNdB. For the 727, this could approach 4.0dB at points on the 90 EPNL contour which are dominated by takeoff noise. For the 737 and DC9 types, this could approach or slightly exceed a 3.5dB reduction.

The above calculated reductions in contour area may be compared with those which might be obtained from other technological fixes in order to gain some

FIGURE 4

737 90 EPNdB CONTOURS, WITH AND WITHOUT MIXER

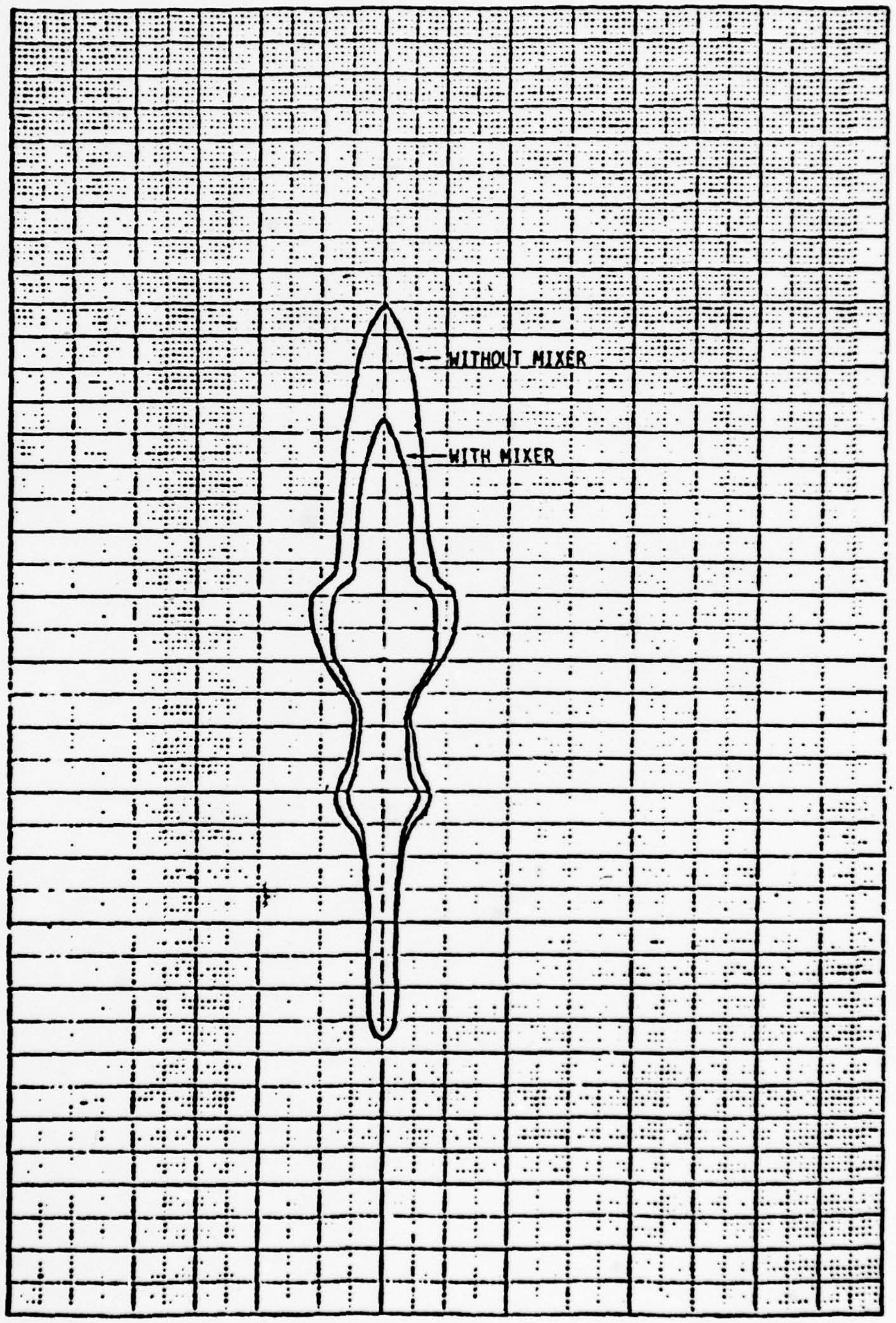


FIGURE 5

737 100 EPNdB CONTOURS, WITH AND WITHOUT MIXER

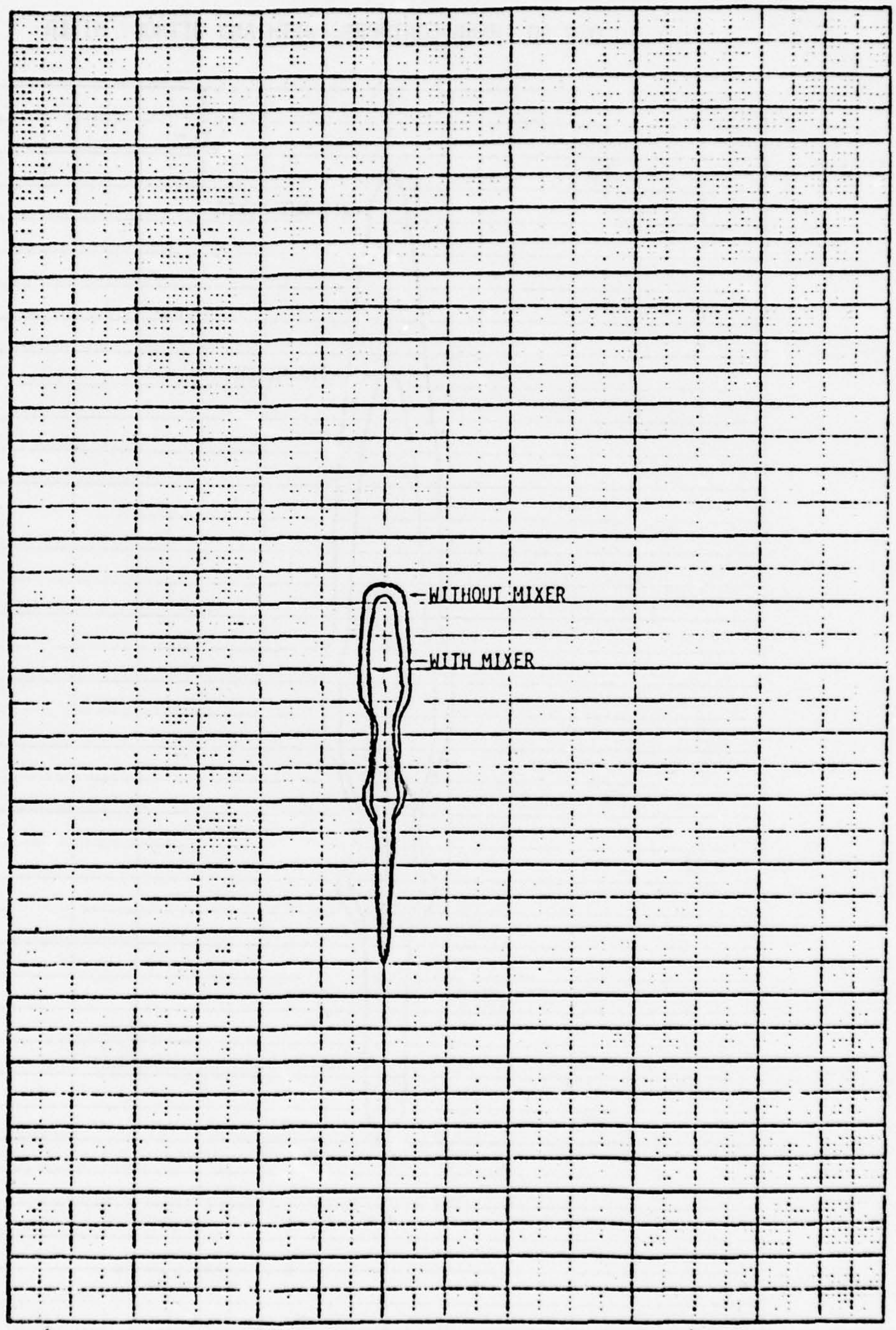


FIGURE 6

DC9 90 EPNdB CONTOURS, WITH AND WITHOUT MIXER

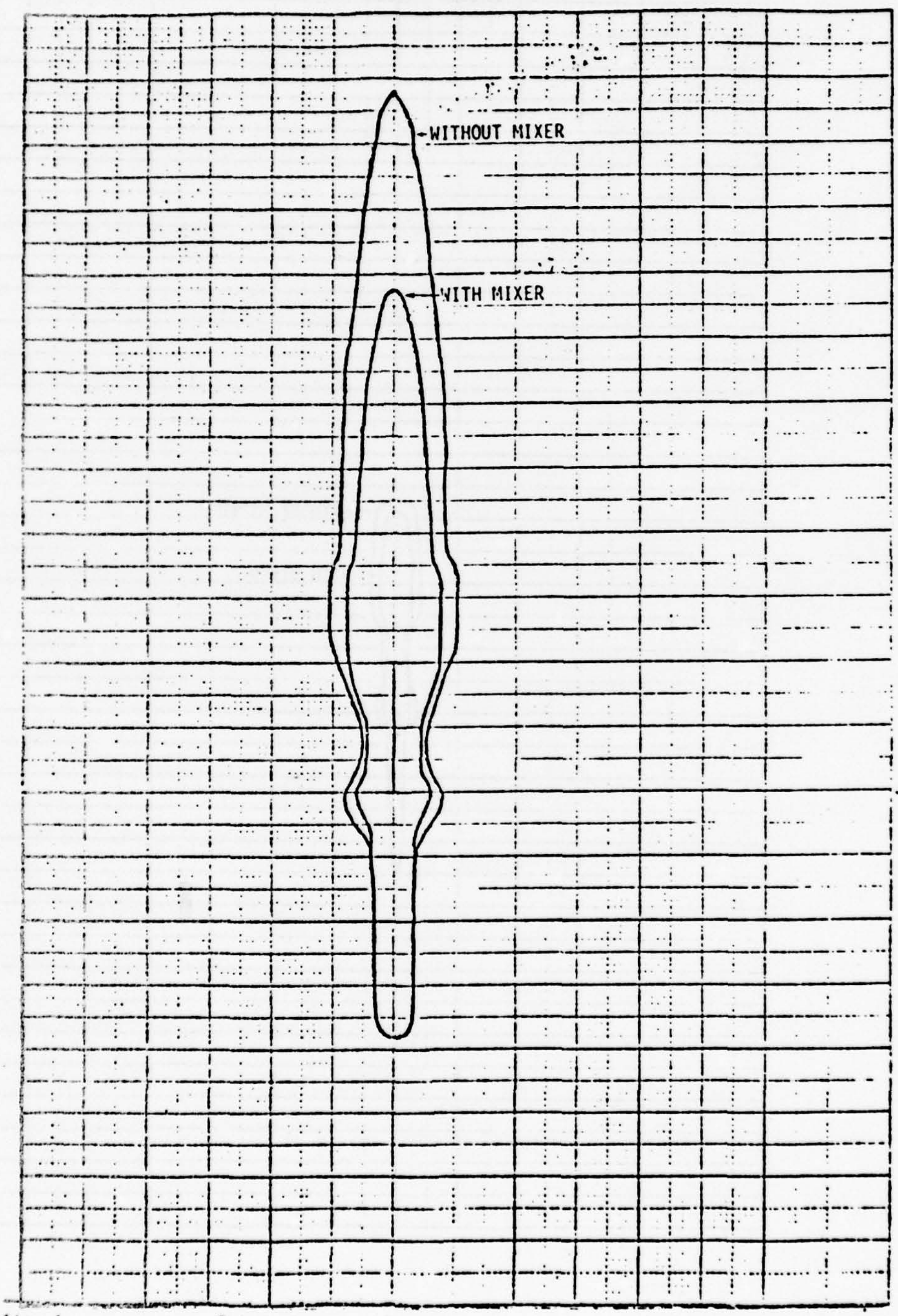


FIGURE 7

DC9 100 EPNdB CONTOURS, WITH AND WITHOUT MIXER

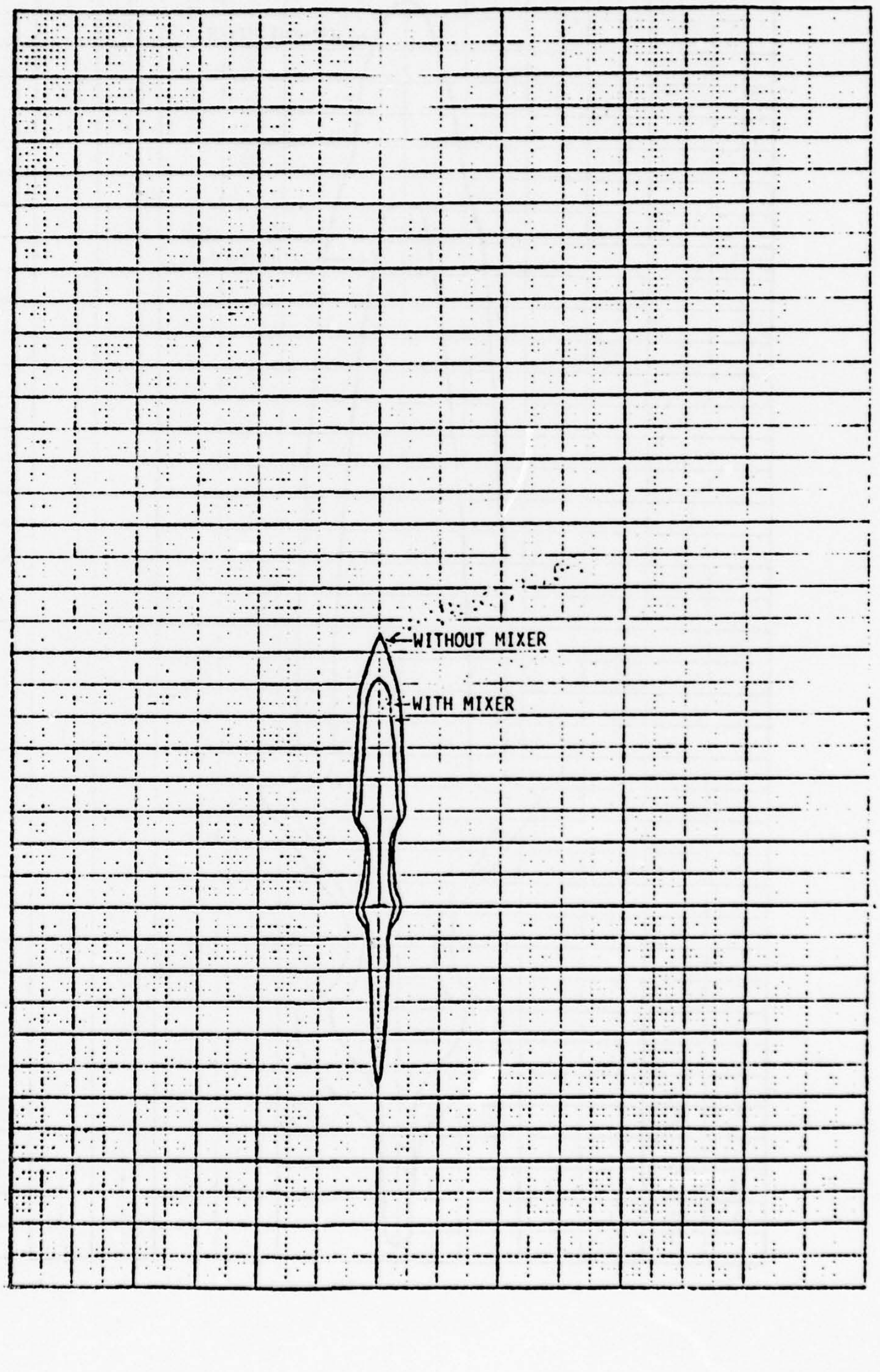


FIGURE 8

727 90 EPNdB CONTOURS, WITH AND WITHOUT MIXER

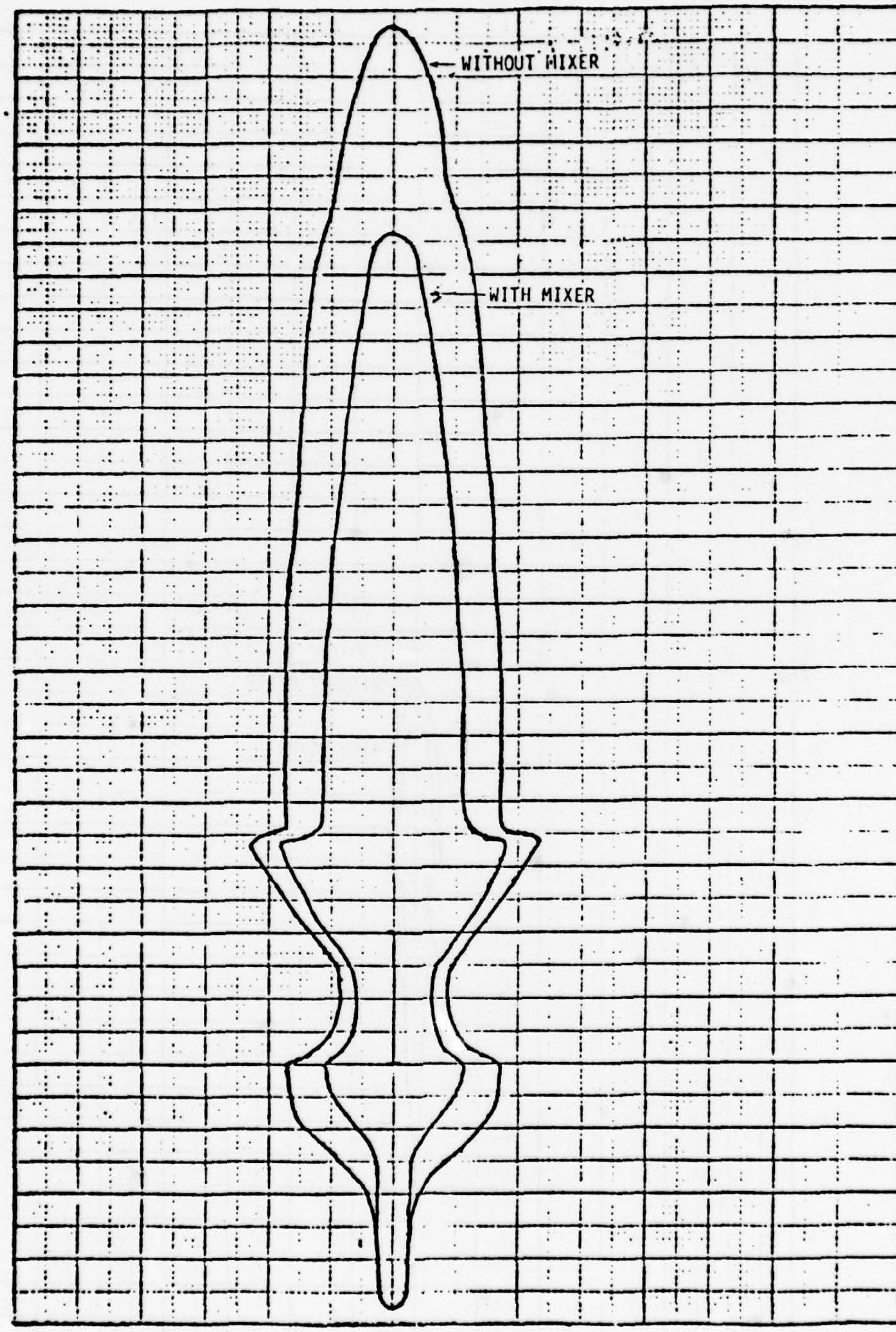
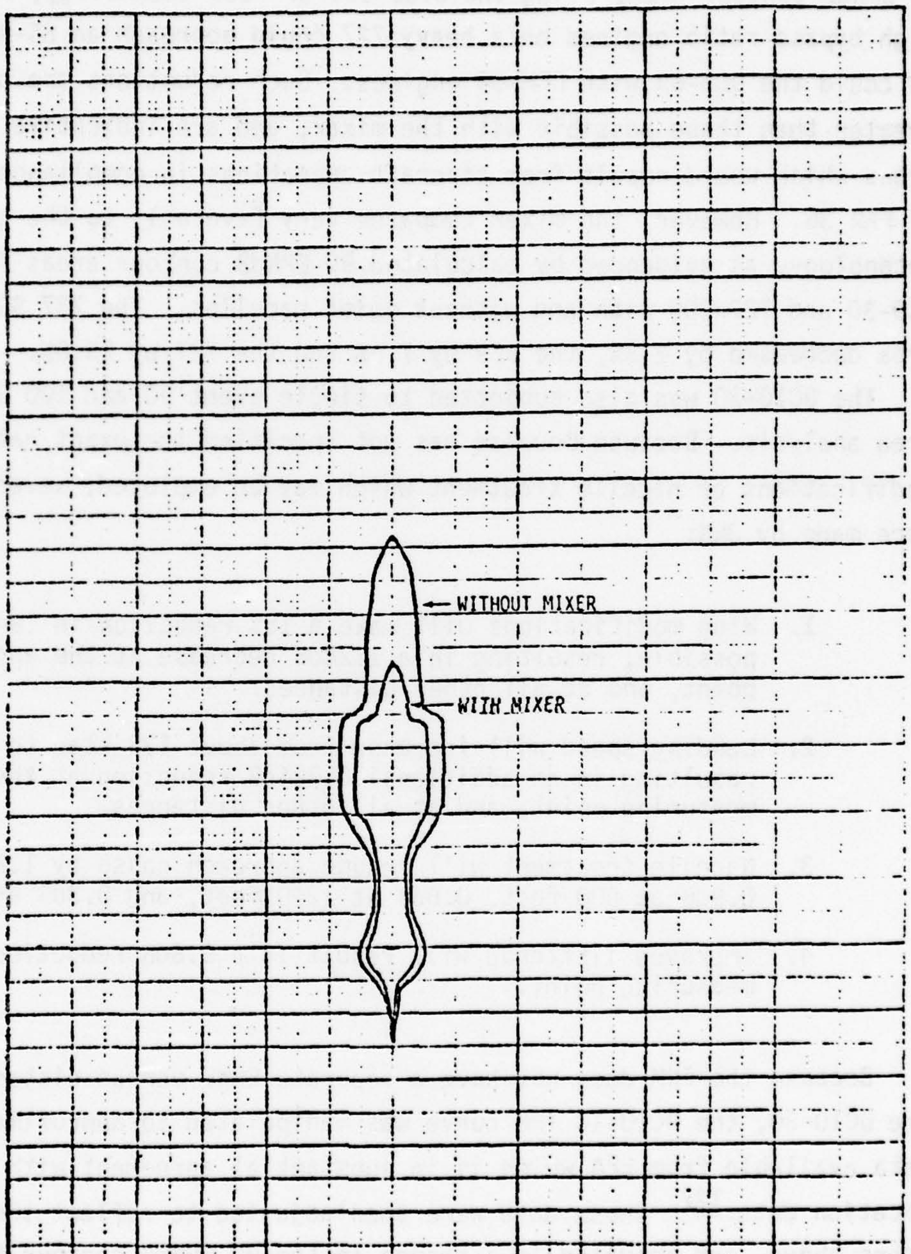


FIGURE 9

727 100 EPNdB CONTOURS, WITH AND WITHOUT MIXER



appreciation of the relative merits of the mixer technology.[11] For example, refanning the 737, DC9, or 727 could result in a 75-85% reduction in 90 EPNdB contour area, using the JT8D-109 or -209 technology, while two larger high bypass ratio engines on a heavy 727 could approach an 85-90% reduction, as could the DC8-63 with CFM-56 engines. Such reductions are significantly greater than those possible with the mixer, and are indicative of the reductions which would result from aircraft operations in compliance with Stage 3 of FAR 36. However, the mixer compares very favorably to the quiet nacelle technology, as evidenced by calculated 90 EPNdB contour areas for the 737-200, DC9-30 and 727-200 with and without quiet nacelles. The 737 90 EPNdB contour area decreased by 2.3%, the DC9 by 7.4% and the 727 by 15.6%.

The DC10-30 was also subjected to single event 90 and 100 EPNdB contour area analysis. Because Douglas has not specified the exact nature of any wing modifications or nacelle treatment which may be employed, several assumptions were made by JWN:

1. Wing modifications will make a 15% reduction in landing thrust possible, resulting in a 1.28dB decrease at the approach measuring point, and at all other distances.

2. Landing speed will increase from about 138 kta. to 145 kta., resulting in an additional 0.224dB reduction at the approach measuring point, and at all other distances.

3. Nacelle treatment will reduce approach noise by 1.2dB at 370 feet, 0.9dB at 800 feet, 0.6dB at 1250 feet, and 0.3dB at 2000 feet.

4. Improved lift/drag will result in a 0.8dB reduction at the takeoff measuring point.

Because the INM does not have a separate EPNL versus distance curve for the DC10-30, the DC10-10 INM curve was manipulated to approximate DC10 noise data available from EPA which is in substantial agreement with DC10-30 certification data.[12] These data were then adjusted to reflect the assumptions above, and resulted in a change in the 90 EPNdB contour from 14.9 to

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[11]Area percentages are derived from the FAA INM.

[12]U.S. EPA, Office of Noise Abatement. "Noise Levels."

12.56 square miles, or about 15.7%. At the 100 EPNdB contour level, the area changed from 3.33 to 2.73 square miles, or about 18%. A current DC10-10 operating at the same stage length generated a 90 EPNdB contour of 6.9 square miles and a 100 EPNdB contour of 1.5 square miles, or about 50% of the area of the DC10-30 which is designed to meet, and not exceed, Stage 3.

POTENTIAL COMMUNITY IMPACT OF REGULATION

The above single event contour analysis is intended to represent the area impact of one aircraft movement. The cumulative impacts of multiple aircraft movements by a typical mixture of aircraft types at four classes of airports have been analyzed using the Noise Exposure Forecast (NEF) metric and the JWN "Area Equivalent Operations" model, in an attempt to estimate the sensitivity of three impact criteria to the replacement of 20% of all current production of 727, 737 and DC9 aircraft with the same aircraft types with mixers. The impact criteria include:

1. Change in 30 NEF contour area,
2. Change in NEF value in decibels, and
3. The percentage increase in aircraft movements which may be added without exceeding the original 30 NEF contour area, due to the introduction of mixer technology, i.e., change in "noise-impact-limited operating capacity."

Previous work done by JWN for the CAB, regarding the environmental impact of airline deregulation (Contract 79-C-64), has resulted in the classification of U.S. aircarrier airports into four categories (see market analysis, above). Each class is represented by a single "average airport" or "AVPORT" which has a runway length, runway utilization percentage, and number of operations (by aircraft type, weight, stage length and time of day) which is representative of the average airport in each class. Forecasts for 1981 resulted in the following 30 NEF impact areas:

CLASS	DAILY OPERATIONS	30 NEF AREA (MI^2)
1	500	58.0
2	100 - 499	18.0
3	50 - 99	6.5
4	10 - 49	1.7

The sensitivity analysis was conducted using the 1981 data base for comparisons of the impact criteria. Although a 20% substitution is obviously not feasible by 1981, the incremental changes resulting from a 1981 analysis should be representative of impacts occurring during the 1980 - 1990 time period, and will tend to slightly overstate the degree of benefit obtained. Table 12 presents the results of substituting 20% of the JT8D powered fleet with aircraft with mixers at each category of airport.

Area reductions and decibel reductions are very small for all classes of airports. The additional operating capacity which may occur without exceeding the base 30 NEF impact area is more significant, and reflects a significant number of aircraft operations at the larger airports. For example, a Class 1 airport with 600 operations could have an 8.7% increase, or 52 additional operations per day without exceeding the base 30 NEF contour of 58.0 square miles. However, this assumes an equal percentage of increase by all aircraft types, which is unlikely. Growth is likely to occur most rapidly in operations by new aircraft which meet Stage 3 standards, or which have mixers, and consequently, the actual increase in noise-impact-limited operating capacity is likely to be greater.

The trend in all three criteria is to show increased benefit with decreasing airport size down to Class 4 where benefits sharply diminish. This is due to the dominance of the 727 in the first three classes where the area equivalent 727 operations increase from 76.8% of all area equivalent operations in Class 1, to 80.5% in Class 2, to 80.7% in Class 3, only to drop sharply to 35.0% in Class 4.

This has some rather profound implications for the 727 aircraft. If all other types were banned from operating at each class of airport, the NEF

TABLE 12

CHANGE IN 30 NEF AREA, NEF LEVEL, AND ADDITIONAL CAPACITY RESULTING FROM A 20% MIXER REPLACEMENT IN THE JT8 POWERED FLEET

CLASS	BASE AREA (MI^2)	NEW AREA (MI^2)	AREA CHANGE (%)	NEF CHANGE (dB)	NEW OPERATIONS NOT EXCEEDING AREA BASE (%)
1	58.00	54.14	-6.64	.3621	8.7
2	18.00	16.88	-7.30	.4121	10.0
3	6.50	5.99	-7.80	.4290	10.4
4	1.70	1.61	-5.30	.3115	7.4

reduction would amount to only 1.14dB for Class 1, 0.94dB for Class 2, and 0.93dB for Class 3, while for Class 4 this would result in a 4.6dB decrease.

ISSUES AND CONCLUSIONS

This section will discuss the major issues associated with early implementation of Stage 3 as determined by JWN through industry contacts. In addition, costs and benefits will be combined and alternative courses of action will be evaluated.

Testing Tolerances and Certification Probability

Aside from the actual noise limits, which may or may not be met by various aircraft and engine technologies, a potentially serious practical problem exists from the aircraft manufacturer's perspective concerning the delicate relationship that exists between business risk, certification testing tolerances and the probability that certification noise levels may not be met during a given test. For some wide-body aircraft, the required noise reductions are close to the tolerances of the certification measuring devices. Therefore, the number of aircraft which may actually meet Stage 3 requirements is uncertain, given the current certification process. This has not been as great a problem in the past because technological improvements were large and margins were greater. Presumably, the industry has entered a phase where incremental technological gains are smaller, and consequently margins exceed testing tolerances in many situations, making it difficult to guarantee new aircraft to meet Stage 3 levels without incurring a substantial business risk.

Contour Area Reductions and Community Impacts

Industry sources recognize that modifications of Stage 2 aircraft to meet Stage 3 limits could result in substantial reductions in single event contour areas. They contend, however, that community noise reductions would hardly be

noticeble. Analysis, done by Boeing and presented to Congress, showed that contour area at La Guardia would be reduced only by the equivalent of 0.4 dB in 1990 based on their fleet projection. JWN analyses tend to confirm that community impacts (in 1990 time frame) will be quite small. On the other hand, substitution of Stage 3 for Stage 2 aircraft at an airport would allow a substantial increase in aircraft operations with no change in noise impacts. This is important since the demand for air transportation is expected to continue to grow over the 1980s. Satisfying this demand with little or no environmental consequences has major economic benefits.

100-Seat Aircraft and the Post-1985 Market

Since the re-engining of small, short-range jet transports does not seem economically feasible, a Stage 3 modification of current production aircraft of this type cannot be accomplished. A small but sustained U.S. market for these aircraft will exist in the post-1985 period assuming no change in regulations. This class of aircraft is required during that time period if service to small and medium sized cities is to be continued without substantial fare increases. The only potential substitute aircraft that will meet Stage 3 is the HS-146, a somewhat unconventional aircraft still in development. A production decision is under review by the British government since no orders for the aircraft have been booked to date.

Stage 3 in 1985 (wide body)

A production cut-off in 1985 for Stage 2 wide body aircraft appears feasible. The DC10-30 presents the most serious problem that can be solved, but at substantial cost. In all cases, alternatives, but perhaps "next-best" aircraft, are available to airline operators.

It is not clear, however, that the production cut-off will lead to a significant reduction in single event contour area. The DC10-30, from our analysis, required a 2.7dB reduction on approach to achieve Stage 3 with trade-offs. This would result in a 15 percent reduction in contour area and an unmeasurable impact on community noise levels. Reductions in contour areas for 747s would be even less. This leads to the conclusion that the proposed regulation would result in considerable expenditures by producers which would have little or no impact on noise problems.

Stage 3 in 1985 (regular body)

Re-engining 2 or 3 ERB aircraft is apparently the only solution to achieve Stage 3 limits. If done, single event contour areas would be reduced dramatically. It appears, however, that with the engines available, the 2 ERB aircraft would grow to DC9-80 size for economic reasons or be too expensive for the low density routes served by the two-engine aircraft.

Stage 2.x in 1983 or 1985

The mixer technology appears to allow regular body aircraft to reduce noise levels significantly at an increase in operating costs of less than one percent. Some development problems remain to be solved, particularly for 727 application. It appears that the mixer technology could be applied to aircraft produced in 1983, but some slippage might be necessary if serious development problems occur.

APPENDIX A

105 AIRPORT SAMPLE DATA

TABLE A-1

105 AIRPORT SAMPLE

ENPLANEMENTS AND DEPARTURES BY TYPE

	ENPLANE-MENTS (000)	DEPARTURES BY AIRCRAFT TYPE									
			WIDE BODY			REGULAR BODY			TURBOPROP		
		TOTAL	4 ENG	3 ENG	2 ENG	4 ENG	3 ENG	2 ENG	4 ENG	2 ENG	OTHER
ROANOKE	380	14,506	0	0	0	0	2,707	5,348	0	6,451	0
MADISON	354	11,461	0	0	0	0	2,937	6,719	0	1,805	0
SAVANNAH	338	5,198	0	0	0	1,415	3,772	11	0	0	0
MOBILE	336	10,474	0	0	0	0	2,448	8,026	0	0	0
MOLINE	331	10,663	0	0	0	24	3,361	5,258	0	2,020	0
TOLEDO	331	7,698	0	0	0	15	3,831	3,849	0	3	0
GREENVILLE	324	8,373	0	0	0	0	2,753	4,656	0	964	0
GREEN BAY	321	10,891	0	0	0	0	0	7,748	0	3,143	0
LEXINGTON	319	8,270	0	0	0	0	2,353	4,772	0	1,145	0
DAYTONA BEACH	317	5,748	0	386	0	0	3,013	2,349	0	0	0
FORT MEYERS	310	4,753	0	0	0	0	4,249	504	0	0	0
HARRISBURGH	309	5,909	0	2	0	237	979	2,932	0	10	1,749
CHATTANOOGA	303	9,493	0	0	0	6	3,900	5,587	0	0	0
AKRON-CANTON	289	7,592	0	0	0	4	1,734	5,837	0	17	0
COLORADO SPRINGS	286	7,724	0	14	0	5	4,756	571	0	2,378	0
AMARILLO	286	7,643	1	0	0	8	4,347	2,606	0	681	0
BILLINGS	282	7,969	164	143	0	0	2,414	3,352	0	716	1,180
ALLENTOWN	273	5,120	0	0	0	0	2,684	2,424	1	8	3
HUNTSVILLE	272	8,377	0	0	0	5	2,065	6,301	0	0	6
SOUIX FALLS	271	11,516	0	1	0	355	1,539	3,670	0	5,951	0
CHARLESTON, W. VA.	267	8,224	0	0	0	5	1,599	4,446	0	2,174	0
PEORIA	266	10,065	0	0	0	0	1,167	7,692	0	1,206	0
CEDAR RAPIDS	257	7,797	0	0	0	13	2,260	4,528	0	996	0
MONTEREY	253	4,730	0	0	0	13	1,838	2,879	0	0	0
FORT WAYNE	250	6,141	0	0	0	20	2,767	3,354	0	0	0

TABLE A-1 (Continued)

	ENPLANEMENTS (000)	DEPARTURES BY AIRCRAFT TYPE									
			WIDE BODY			REGULAR BODY			TURBOPROP		
		TOTAL	4 ENG	3 ENG	2 ENG	4 ENG	3 ENG	2 ENG	4 ENG	2 ENG	OTHER
BATON ROUGE	245	7,455	0	0	0	0	2,914	4,541	0	0	0
EVANSVILLE	244	5,723	0	0	0	0	1,046	4,677	0	0	0
TALLAHASSEE	237	6,576	0	0	0	45	1,534	5,042	0	0	0
MONTGOMERY	234	7,452	0	0	0	0	2,601	1,756	0	0	0
PORTLAND	232	5,936	0	0	0	2	2,801	1,532	0	761	840
SOUTH BEND	226	6,242	0	0	0	18	1,760	2,784	0	1,680	0
BRISTOL/TRI CITIES	224	9,621	0	0	0	0	1,026	5,411	0	2,614	570
SAGINAW	222	5,828	0	0	0	16	1,288	3,794	0	730	0
LINCOLN	220	9,232	0	0	0	12	2,231	4,262	0	2,727	0
LANSING	218	8,320	0	0	0	14	1,149	2,788	0	2,369	0
CORPUS CHRISTI	203	3,583	0	0	0	0	2,178	1,399	0	6	0
EUGENE	203	4,612	0	0	0	0	13	4,596	0	3	0
AUSTIN	193	9,941	0	0	0	0	6,123	3,816	0	2	0
PALM SPRINGS	188	3,355	0	17	0	711	1,246	1,381	0	0	0
SANTA BARBARA	183	2,937	0	0	0	0	1,345	1,586	0	6	0
MELBOURNE	183	4,091	0	0	0	0	2,441	1,650	0	0	0
SPRINGFIELD, MO	181	6,812	0	0	0	0	728	5,615	0	469	0
ASHVILLE	179	7,241	0	0	0	2	556	4,602	0	2,081	0
COLUMBUS, GA	172	5,941	0	0	0	0	11	5,929	0	0	1
BURLINGTON, VT	170	5,140	0	0	0	0	159	3,295	0	1,166	520
SCRANTON/SILKES BARRE	162	3,433	0	0	0	0	1,347	2,083	1	0	2
NEWPORT NEWS	161	4,566	0	0	0	4	828	2,519	0	1,215	0
FAYETTEVILLE, NC	161	5,872	0	0	0	0	1,732	3,034	0	1,106	0
GRAND JUNCTION	159	3,881	0	0	0	185	1,102	822	0	1,772	0

TABLE A-1 (Continued)

	ENPLANE-MENTS (000)	DEPARTURES BY AIRCRAFT TYPE										
			WIDE BODY			REGULAR BODY			TURBOPROP		
		TOTAL	4 ENG	3 ENG	2 ENG	4 ENG	2 ENG	3 ENG	4 ENG	2 ENG	OTHER
FARGO	155	5,280	2	2	0	0	2,133	1,820	0	1,323	0
ROCHESTER, MN	152	6,387	1	1	0	0	2,506	2,045	0	1,834	0
RAPID CITY	149	5,324	0	0	0	0	4	4,586	0	734	0
GREAT FALLS	140	4,590	3	123	0	78	1,493	2,893	0	0	0
ERIE	140	3,549	0	0	0	0	74	3,469	0	4	2
FLINT	140	4,868	0	0	0	13	886	2,598	0	1,371	0
YOUNGSTOWN	138	4,096	0	0	0	21	849	2,677	0	153	396
BANGOR	138	2,750	0	0	0	0	1,781	969	0	0	0
BAKERSFIELD	137	3,247	0	0	0	0	256	2,991	0	0	0
DULUTH	136	6,028	0	0	0	0	4,749	1,279	0	0	0
GAINSVILLE	135	1,817	0	0	0	0	355	1,462	0	0	0
ASHLAND/HUNTINGTON	130	4,837	0	0	0	0	333	2,408	0	2,096	0
CASPER	129	4,204	0	0	0	0	25	3,501	0	678	0
CHAMPAIGN	129	4,962	0	0	0	0	0	3,377	0	1,585	0
BISMARK	128	5,038	0	0	0	0	1,534	1,780	0	1,438	286
KALAMAZOO	128	4,900	0	0	0	0	0	2,218	0	2,682	0
SPRINGFIELD, IL	127	5,735	0	0	0	0	0	4,277	0	1,458	0
MEDFORD	123	2,416	0	0	0	0	5	2,411	0	0	0
WATERLOO	119	5,882	0	0	0	0	0	3,477	0	2,405	0
MONROE	117	4,923	0	0	0	0	2,246	2,575	0	102	0
ELGIN	115	4,409	0	0	0	0	0	4,409	0	0	0
LAFAYETTE, LA	115	3,042	0	0	0	0	0	3,038	0	4	0
JOPLIN	113	3,954	0	0	0	0	0	1,542	0	2,412	0
MISSION	113	2,127	0	0	0	0	0	2,127	0	0	0
SOUIX CITY	113	7,567	0	0	0	0	0	4,678	0	2,889	0

TABLE A-1 (Continued)

	ENPLANE-MENTS (000)	DEPARTURES BY AIRCRAFT TYPE									
			WIDE BODY			REGULAR BODY			TURBOPROP		
		TOTAL	4 ENG	3 ENG	2 ENG	4 ENG	3 ENG	2 ENG	4 ENG	2 ENG	OTHER
GRAND FORKS	103	5,385	0	0	0	0	871	2,512	0	2,002	0
ACARTA/EUREKA	102	2,059	0	0	0	0	0	1,707	0	352	0
PASCO	100	2,954	0	0	0	0	0	2,954	0	0	0
MACON	98	2,185	0	0	0	0	10	2,175	0	0	0
WASSAU	98	4,593	0	0	0	0	0	3,216	0	1,377	0
FORT SMITH	93	6,510	0	0	0	0	1,425	970	0	4,115	0
IDAHO FALLS	92	2,453	0	0	0	0	0	2,453	0	0	0
GULFPORT	91	3,605	0	0	0	0	0	3,605	0	0	0
MUSKEGON	85	4,082	0	0	0	0	10	1,769	0	2,303	0
WILMINGTON, NC	85	4,718	0	0	0	0	345	1,910	0	2,463	0
TRAVERSE CITY	84	3,082	0	0	0	0	0	1,935	0	1,147	0
MYRTLE BEACH	83	3,634	0	0	0	0	0	1,812	0	1,822	0
MISSOULA	82	2,366	0	0	0	0	1,082	1,284	0	0	0
PANAMA CITY	78	3,439	0	0	0	0	533	2,906	0	0	0
BEAUMONT	75	2,288	0	0	0	0	571	1,714	0	3	0
BINGHAMPTON	73	2,579	0	0	0	0	32	1,220	0	1,327	0
DOTHAN	72	2,807	0	0	0	0	0	2,804	0	0	3
ELMIRA	71	2,956	0	0	0	0	13	1,228	0	1,715	0
ALEXANDRIA, LA	70	2,956	0	0	0	0	2,061	769	0	129	0
MINOT	70	2,813	0	0	0	0	0	1,796	0	719	298

TABLE A-1 (Continued)

	ENPLANE-MENTS (000)	TOTAL	DEPARTURES BY AIRXRAFT TYPE								
			WIDE BODY			REGULAR BODY			TURBOPROP		
			4 ENG	3 ENG	2 ENG	4 ENG	3 ENG	2 ENG	4 ENG	2 ENG	OTHER
OSHKOSH	70	3,831	0	0	0	0	0	1,142	0	2,689	0
TOPEKA	67	4,180	0	0	0	0	0	1,836	0	2,344	0
ALBANY, GA	66	2,759	0	0	0	0	0	2,745	0	0	14
CHARLOTTESVILLE	66	3,216	0	0	0	0	327	1,007	0	1,882	0
COLUMBIA, MO	65	3,538	0	0	0	0	0	1,325	0	2,213	0
JOPLIN	65	3,954	0	0	0	0	0	1,542	0	2,412	0
ITHACA	65	3,018	0	0	0	0	5	985	0	2,028	0
BOZEMAN	64	2,247	0	0	0	0	924	1,320	0	1	2
POCATELLO	63	2,884	0	0	0	0	0	2,884	0	0	0
SMITH/REYNOLDS	61	4,859	0	0	0	0	686	1,754	0	2,419	0

TABLE A-2

SAMPLE STRATIFIED BY ENPLANEMENTS

PASSENGER RANGE	AIRPORTS	TOTAL	LARGE	3 ERB	2 ERB	2 ETP	COMMUTER	TOTAL ENPLANEMENTS (000)
350 plus	2	25,967	0	5,644	12,067	8,256	0	734
300-349	11	87,470	2,085	30,659	45,692	7,285	1,749	3,539
250-299	12	92,898	751	29,170	47,660	14,127	1,190	3,252
200-249	13	84,937	107	22,156	50,374	10,890	1,410	2,940
150-199	14	74,877	925	22,257	40,197	10,974	524	2,399
100-149	26	110,663	238	15,461	71,915	22,365	684	3,257
61-99	27	91,555	0	8,024	50,106	33,108	317	2,052
TOTAL	105	568,367	4,106	133,371	318,011	107,005	5,874	18,173

TABLE A-3

RELATIONSHIPS BETWEEN PASSENGERS AND SEATS

PASSENGER RANGE	AVERAGE ENPLANEMENTS	AVERAGE DEPARTURES	PASSENGERS PER DEPARTURE	SEATS PER DEPARTURE	PASSENGERS PER SEAT
350 plus	367,000	12,983	28.3	84.3	.34
300-349	321,700	7,952	40.5	98.0	.41
250-299	271,000	7,742	35.0	93.8	.37
200-249	226,150	6,534	34.6	92.2	.38
150-199	171,360	5,348	32.0	93.8	.34
100-149	125,300	4,256	29.4	86.9	.34
61-99	76,000	3,391	22.4	78.8	.28
AVERAGE	173,076	5,413	32.0	90.0	.355

TABLE A-4

LOCAL-TRUNK SPLIT FOR SAMPLE AIRPORTS

PASSENGE RANGE	AIRPORT SERVICE				ENPLANEMENTS (000)		
	TOTAL	TRUNKS	LOCAL	MIXED	TOTAL	TRUNKS	LOCAL
350 and More	2	0	0	2	734	118	616
300 - 349	11	3	1	7	3,539	2,544	995
250 - 299	12	1	0	11	3,252	2,101	1,151
200 - 249	13	2	1	10	2,940	2,086	854
150 - 199	14	1	1	12	2,399	1,380	1,019
100 - 149	26	2	13	11	3,257	1,162	2,095
61 - 99	27	1	17	9	2,052	369	1,683
TOTAL	105	10	33	62	18,173	9,760	8,413